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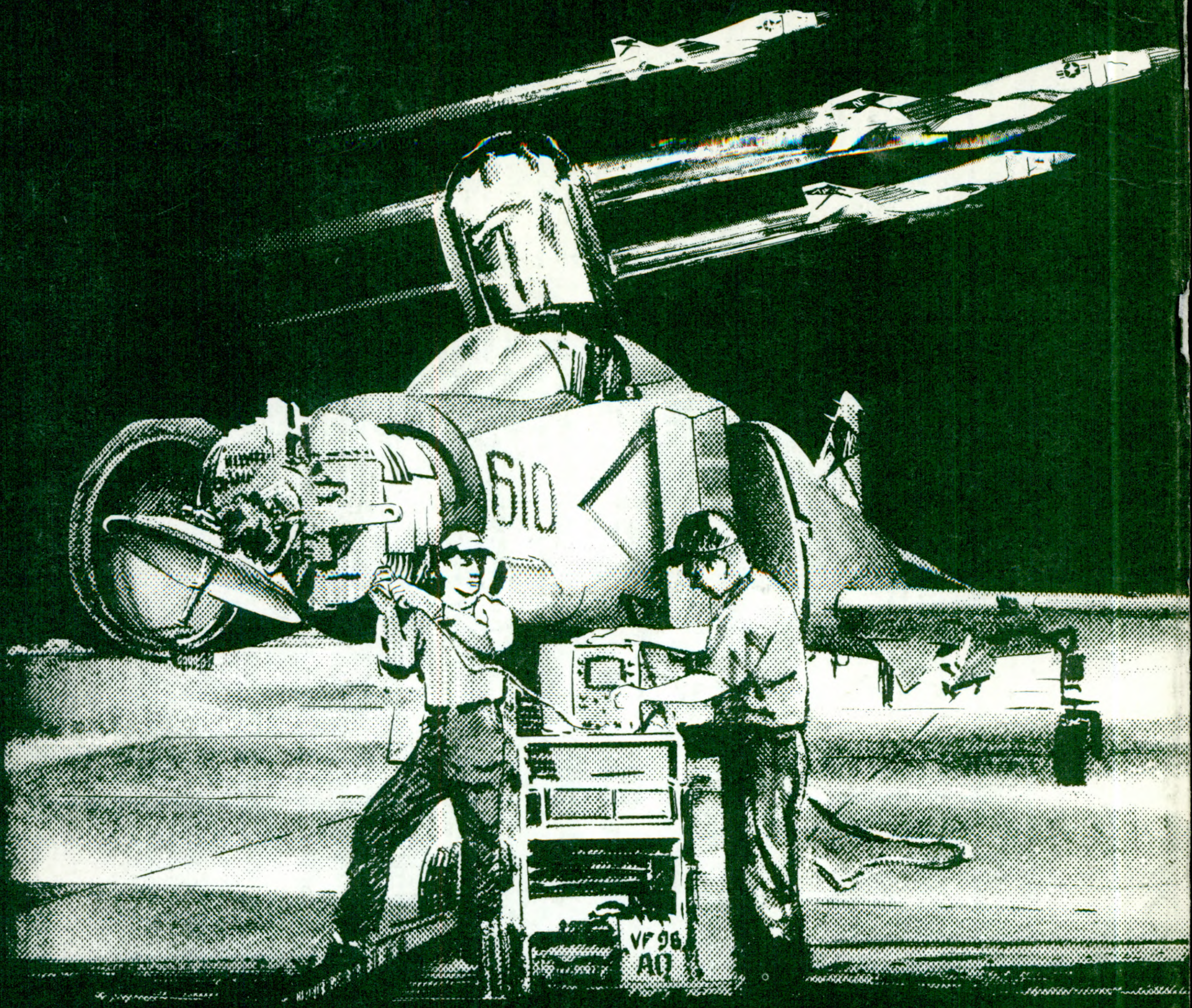

AVIATION

FIRE CONTROL TECHNICIAN 1 & C

BUREAU OF NAVAL PERSONNEL

RATE TRAINING MANUAL NAVPERS 10390-B

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PREFACE

This Rate Training Manual is one of a series of training manuals prepared especially for enlisted personnel of the U.S. Navy and Naval Reserve who are preparing for advancement to AQ1 and AQC.

This Manual of Qualifications for Advancement, NavPers 18068-B (Revised), has been used as a guide in the selection of content for this training manual. Trainees should become familiar with the qualifications for advancement prior to starting work on this manual.

Of the 17 chapters in this training manual, 16 are concerned with the technical aspects of the AQ rating. Chapter 1 contains introductory information with which the trainee should familiarize himself before studying the other chapters.

Basic Electricity, NavPers 10086 (current edition), and Basic Electronics, NavPers 10087 (current edition), contain essential background information for the AQ rating.

This training manual has been prepared by the Navy Training Publications Center, Millington, Tennessee, for the Bureau of Naval Personnel. Credit is given to the Naval Air Technical Training Center, located at Millington, Tennessee, the Naval Examining Center, Great Lakes, Illinois, and to the Naval Air Systems Command, for technical reviews.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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READING LIST

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Educational Services Officer.* The following courses are recommended:

D-166	Advanced Algebra
D-177	Geometry II
D-188	Trigonometry
E-291	Physics II
A-424	Intermediate College Algebra
C-517	College Physics
F-544	Personnel Management

* "Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified on the active duty orders."

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CHAPTER 1

AVIATION FIRE CONTROL TECHNICIAN RATING

This training manual is designed to aid the AQF2 and the AQB2 in preparing for advancement to AQ1 and the AQ1 in preparing for advancement to AQC. It is based primarily on the professional requirements of qualifications for AQ1 and AQC, as specified in the Manual of Qualifications for Advancement, NavPers 18068 (Series), through Change No. 4. Therefore, subsequent changes in the qualifications may not be reflected in the information given in this training manual. In preparing for the examination for advancement, this manual should be studied in conjunction with Military Requirements for Petty Officers 1 & C, NavPers 10057 (Series).

Most of the contents of this training manual involves the technical subject matter with which the Aviation Fire Control Technician must become proficient. Other areas covered include the responsibilities required of the senior AQ's concerning maintenance organization, administration, supervision, and procedures. Supply is also discussed, but only at a level of familiarization which is necessary for all naval personnel who are concerned with maintenance.

ENLISTED RATING STRUCTURE

The present enlisted rating structure includes two types of ratings: general ratings and service ratings.

GENERAL RATINGS are designed to provide paths of advancement and career development. A general rating identifies a broad occupational field of related duties and functions requiring similar aptitudes and qualifications. General ratings provide the primary means used to identify billet requirements and personnel qualifications. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

Subdivisions of certain general ratings are identified as SERVICE RATINGS. These service ratings identify areas of specialization within the scope of a general rating. Service ratings are established in those general ratings in which specialization is essential for efficient utilization of personnel. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

AQ RATING

AQ1 and AQC are rates within the AQ general rating and are included in the Navy Occupational Group IX (Aviation) ratings.

Where occupational content is related, general ratings have been combined at the E-8 and E-9 levels to form broader occupational fields. In the AQ rating, in order to advance to Senior Chief Petty Officer (E-8), Chief Petty Officers (E-7) will be required to become conversant with the duties and responsibilities of the other avionics ratings (AE, AX, and AT).

At pay grade E-9, the AQ rating loses its identity; all of the avionics ratings are compressed into one rating at the E-9 level. The AECS, AQCS, ATCS, or AXCS who is selected for advancement becomes a Master Chief Avionics Technician (AVCM). Figure 1-1 illustrates the paths of advancement from Recruit to Master Chief Avionics Technician, Warrant Officer, or Limited Duty Officer.

Shaded areas in figure 1-1 indicate places in the enlisted path of advancement where qualified men may advance to Warrant Officer (W-1), or selected Commissioned Warrant Officers (W-2 or W-3) may advance to Limited Duty Officer. Personnel in enlisted rates and warrant ranks not in the shaded area (fig. 1-1) may advance only as indicated by the connecting arrows.

Additional information concerning promotion to Warrant or Commissioned Officer is presented later in this chapter.

The Manual of Qualifications for Advancement, NavPers 18068 (Series) establishes the AQ's responsibility for the maintenance and inspection of the weapons system and related equipment including armament control radars. computers, computing sights, gyroscopes, and periscopes.

In addition, the AQ is responsible for insuring that all test equipment is in operating condition, and that any repairs or calibration needed is performed in accordance with current instructions.

Assignments available to the AQ's vary widely. In addition to the various types of maintenance activities to which lower rated personnel are assigned (discussed in AQ 3 & 2, NavPers 10387), Second Class and above are eligible for assignment to instructor duty as well as a number of other desirable shore billets. Most of these billets are under the management control of BuPers and are directly associated with training. Others are associated with research, testing, or evaluation. Some of the more desirable billets to which the AQ may be assigned are described in the following paragraphs.

Instructor duty is available at the Naval Air Technical Training Center, Millington, Tennessee, in the following schools:

1. Avionics Technician Course (Class A).
2. Aviation Fire Control Technician School (Class A).
3. Advanced First Term Avionics Course (Class B).
4. Avionics Advanced Course (Class B).
5. Aviation Officers School (Class O).

In addition to the above listed instructor billets, the AQ may be assigned to instructor duty with a Naval Air Maintenance Training Unit (NAMTU). NAMTU's are located at shore stations on both coasts. Personnel assigned to this duty are first sent to Naval Air Maintenance Training Group headquarters at Millington, Tennessee, for a period of indoctrination and instruction.

Instructor billets are normally filled on a voluntary basis. Detailed information concerning assignment to instructor duty is contained in the Enlisted Transfer Manual, NavPers 15909 (Series).

Chief Aviation Fire Control Technicians are also eligible for assignment to duty with the Naval Examining Center, Great Lakes, Illinois, as Item Writers. CPO's assigned to the Examining Center assist in the preparation of Navy-wide advancement examinations for enlisted personnel.

Senior Chief Aviation Fire Control Technicians are eligible for assignment to duty with the Navy Training Publications Center (NTPC) NAS, Millington, as Technical Writers. CPO's assigned to NTPC assist in the preparation and revision of Rate Training Manuals and/or Correspondence Courses for the avionics ratings.

There are a number of special programs and projects to which enlisted personnel may be assigned. Some of these involve research; others may involve testing or evaluation. An example of such an assignment is with the Weapons Personnel Research Branch (WPRB), NATC, Patuxent River, Maryland. Their mission is to develop recommended personnel requirements for squadrons operating and maintaining the latest types of weapons systems.

For a listing of other special programs and projects, reference should be made to the Enlisted Transfer Manual. Others are also announced from time to time in BuPers Notices.

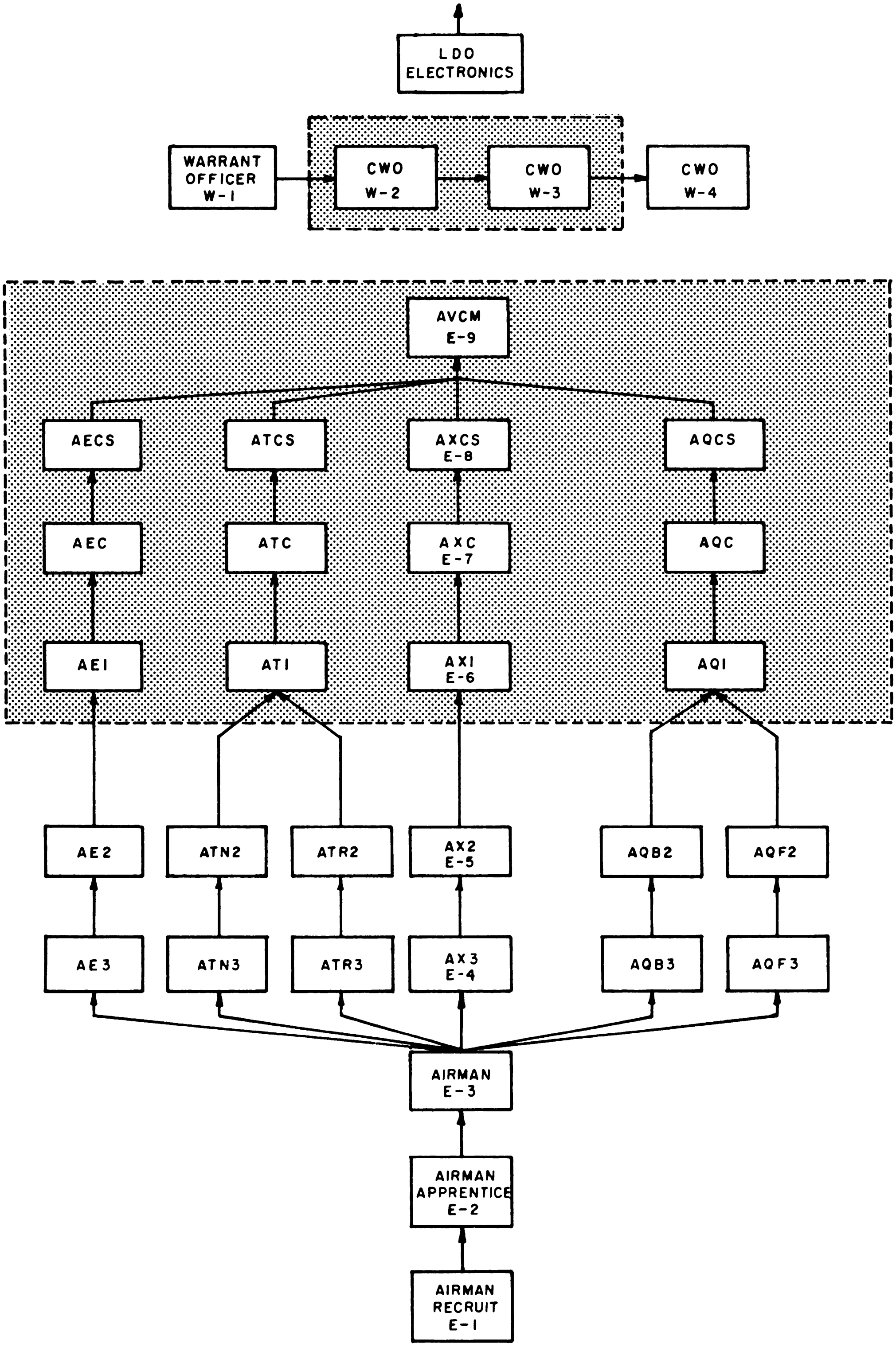
Personnel may indicate their desire for assignment to a specific program or project by indicating it in the "remarks" block of their Rotation Data Card.

As a petty officer, you are already aware of the importance of the AQ rating to naval aviation. Pilots and aircrewmen depend upon the AQ for the efficient operation of the systems for which he is responsible. As improved weapons systems are developed, the AQ's job involves new and greater responsibilities; from the lowest level up, he must possess greater technical skills than ever before.

When advanced to AQ1 or AQC, even more responsibilities are to be yours; in other words, you must possess more than technical skills. You must assume greater responsibility not only for your own work, but also for the work of others who serve under you. Briefly, the AQ1 or AQC must be a skilled technician, supervisor, inspector, and instructor, as well as an accomplished military leader. First class and chief petty officers are therefore vitally concerned with the Naval Leadership Program.

As a result of the Naval Leadership Program, a considerable amount of material related to naval leadership for first class and chief petty officers is available. Studying this material will make you aware of your many leadership responsibilities as a first class or chief petty officer and will also be of great help in developing leadership qualities. It will not in itself, however, make you a good leader. Leadership principles can be taught, but a good leader acquires the quality of leadership only through hard work and practice.

As you study this material concerning leadership traits, keep in mind that probably none of our most successful leaders possessed all of these traits to a maximum degree, but a weakness in some traits was more than compensated for by strength in others. Critical self-evaluation will enable you to realize the traits in which you are strong, and to capitalize on them.



AE. 1

Figure 1-1.–Path of advancement.

At the same time you must constantly strive to improve on the traits in which you are weak.

Your success as a leader will be decided, for the most part, by your achievements in inspiring others to learn and perform. This is best accomplished by personal example.

Since the AQ rating includes service ratings at the AQ3 and AQ2 levels, it is necessary to consider the transition from service ratings to the general rating. This is important from the following two points of view:

1. Personnel going from a service rating to the general rating must broaden the scope of their knowledge. For example, an AQF2 cannot advance to AQ1 without learning the duties of the AQB2.
2. The AQ1 and the AQC have responsibilities for cross-training personnel seeking advancement from a service rating to the general rating.

ADVANCEMENT

By this time, you are probably well aware of the personal advantages of advancement—higher pay, greater prestige, more interesting and challenging work, and the satisfaction of getting ahead in your chosen career. By this time, also, you have probably discovered that one of the most enduring rewards of advancement is the training you acquire in the process of preparing for advancement.

The Navy also profits by your advancement. Highly trained personnel are essential to the functioning of the Navy. By advancement, you increase your value to the Navy in two ways: First, you become more valuable as a person who can supervise, lead, and train others and second, you become more valuable as a technical specialist and thus make far-reaching contributions to the entire Navy.

Since you are studying for advancement to PO1 or CPO, you are probably already familiar with the requirements and procedures for advancement. However, you may find it helpful to read the following sections. The Navy does not stand still. Things change all the time, and it is possible that some of the requirements have changed since the last time you went up for advancement. Furthermore, you will be responsible for training others for advancement; therefore, you will need to know the requirements in some detail.

HOW TO QUALIFY FOR ADVANCEMENT

To qualify for advancement, a person must:

1. Have a certain amount of time in grade.
2. Complete the required military and professional training manuals.
3. Demonstrate the ability to perform all the PRACTICAL requirements for advancement by completing applicable portions of the Record of Practical Factors, NavPers 1414/1 (formerly NavPers 760).
4. Be recommended by his commanding officer.
5. Demonstrate his KNOWLEDGE by passing a written examination on (a) military requirements, and (b) professional qualifications.

Some of these general requirements may be modified in certain ways. Figure 1-2 gives an overall view of the requirements for advancement of active duty personnel; figure 1-3 gives this information for inactive duty personnel.

Remember that the requirements for advancement can change. Check with your educational services office to be sure that you know the most recent requirements.

When you are training lower rated personnel, it is a good idea to point out that advancement is not automatic. Meeting all the requirements makes a person ELIGIBLE for advancement. Such factors as the score made on the written examination, length of time in service, performance marks, and quotas enter into the final determination of who will actually be advanced.

HOW TO PREPARE FOR ADVANCEMENT

Preparation for advancement includes studying the qualifications, working on the practical factors, studying the required Rate Training Manuals, and studying any other material that may be specified. To prepare yourself for advancement or to help others prepare for advancement, you will need to be familiar with (1) the "Quals" Manual, (2) the Record of Practical Factors, NavPers 1414/1, (3) a NavPers publication called Training Publications for Advancement, NavPers 10052 (Series), and (4) Rate Training Manuals. The following sections describe these materials and give some information on how to use them to the best advantage.

"Quals" Manual

The Manual of Qualifications for Advancement, NavPers 18068 (Series), gives the minimum requirements for advancement to each rate within each rating. This manual is usually called the "Quals" Manual, and the qualifica-

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	E1 to E2	E2 to E3	#† E3 to E4	# E4 to E5	† E5 to E6	† E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5.	36 mos. as E-6. 8 years total enlisted service.	36 mos. as E-7. 8 of 11 years total service must be enlisted.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3, PT3, AME 3, HM 3			Class B for AGC MUC, MNC.		
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 1414/1, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS **	Locally prepared tests.	See below.	Navy-wide examinations required for all PO advancements.				Navy-wide, selection board.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		

* All advancements require commanding officer's recommendation.

† 1 year obligated service required for E-5 and E-6; 2 years for E-6, E-7, E-8 and E-9.

# Military leadership exam required for E-4 and E-5.

** For E-2 to E-3, NAVEXAMCEN exams or locally prepared tests may be used.

Figure 1-2.—Active duty advancement requirements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
TOTAL TIME IN GRADE	4 mos.	6 mos.	15 mos.	18 mos.	24 mos.	36 mos.	36 mos.	24 mos.
TOTAL TRAINING DUTY IN GRADE †	14 days	14 days	14 days	14 days	28 days	42 days	42 days	28 days
PERFORMANCE TESTS			Specified ratings must complete applicable performance tests before taking examination.					
DRILL PARTICIPATION	Satisfactory participation as a member of a drill unit.							
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)	Record of Practical Factors, NavPers 1414/1, must be completed for all advancements.							
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)	Completion of applicable course or courses must be entered in service record.							
EXAMINATION	Standard Exam	Standard Exam or Rating Training.	Standard Exam required for all PO Advancements.				Standard Exam, Selection Board. Also pass Mil. Leadership Exam for E-4 and E-5.	
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center				Bureau of Naval Personnel	

* Recommendation by commanding officer required for all advancements.

† Active duty periods may be substituted for training duty.

Figure 1-3. –Inactive duty advancement requirements.

tions are of two general types: (1) military requirements, and (2) professional or technical qualifications. Military requirements apply to all ratings rather than to any one rating alone. Professional qualifications are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject matter groups. Then, within each subject matter group, they are divided into PRACTICAL FACTORS and KNOWLEDGE FACTORS.

The qualifications for advancement and a bibliography of study materials are available in your educational services office. The "Quals" Manual is changed more frequently than Rate Training Manuals are revised. By the time you are studying this training manual, the "quals" may have been changed. Never trust any set of "quals" until you have checked the change number against an UP-TO-DATE copy of the "Qauls" Manual.

In training others for advancement, emphasize these three points about the "quals":

1. The "quals" are the MINIMUM requirements for advancement. Personnel who study MORE than the required minimum will have a great advantage when they take the written examinations for advancement.

2. Each "qual" has a designated rate level–chief, first class, second class, or third class. You are responsible for meeting all "quals" specified for the rate level to which you are seeking advancement AND all "quals" specified for lower rate levels.

3. The written examinations for advancement will contain questions relating to the practical factors AND to the knowledge factors of BOTH the military requirements and the professional qualifications.

Record of Practical Factors

A special form known as the Record of Practical Factors, NavPers 1414/1, is used to record the satisfactory performance of the practical factors. This form lists all military and all professional practical factors. Whenever a person demonstrates his ability to perform a practical factor, appropriate entries must be made in the DATE and INITIAL columns. As a PO1 or CPO, you will often be required to check the practical factor performance of lower rated personnel and to report the results to your supervising officer.

As changes are made periodically to the "Quals" Manual, new forms of NavPers 1414/1 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes to the "Quals" Manuals. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rate but which are not identified as minimum qualifications for advancement. Keep this in mind when you are training and supervising other personnel. If a person demonstrates proficiency in some skill which is not listed in the "quals" but which is within the general scope of the rate, report this fact to the supervising officer so that an appropriate entry can be made in the Record of Practical Factors.

When you are transferred, the Record of Practical Factors should be forwarded with your service record to your next duty station. It is a good idea to check and be sure that this form is actually inserted in your service record before you are transferred. If the form is not in your record, you may be required to start all over again and requalify in practical factors that have already been checked off. You should also take some responsibility for helping lower rated personnel keep track of their practical factor records when they are transferred.

A second copy of the Record of Practical Factors should be made available to each man in pay grades E-3 through E-8 for his personal record and guidance.

NavPers 10052

Training Publications for Advancement, NavPers 10052 (Series) is a very important publication for anyone preparing for advancement. This publication lists required and recommended Rate Training Manuals and other reference material to be used by personnel working for advancement. NavPers 10052 (Series) is revised and issued once each year by the Bureau of Naval Personnel. Each revised edition is identified by a letter following the NavPers number. When using this publication, be SURE you have the most recent edition.

The required and recommended references are listed by rate level in NavPers 10052 (Series). It is important to remember that you are responsible for all references at lower rate levels, as well as those listed for the rate to which you are seeking advancement.

Rate Training Manuals that are marked with an asterisk (*) in NavPers 10052 (Series) are MANDATORY at the indicated rate levels. A mandatory training manual may be completed by (1) passing the appropriate Enlisted Correspondence Course that is based on the mandatory training manual, (2) passing locally prepared tests based on the information given in the mandatory training manual; or (3) in some cases, successfully completing an appropriate Navy school.

When training personnel for advancement, do not overlook the section of NavPers 10052 (Series) which lists the required and recommended references relating to the military requirements for advancement. All personnel must complete the mandatory military requirements training manual for the appropriate rate level before they can be eligible to advance. Also, make sure that personnel working for advancement study the references which are listed as recommended but not mandatory in NavPers 10052 (Series). It is important to remember that ALL references listed in NavPers 10052 (Series) may be used as source material for the written examinations, at the appropriate levels.

Rate Training Manuals

There are two general types of Rate Training Manuals. Manuals (such as this one) are prepared for most enlisted rates and ratings, giving information that is directly related to the professional qualifications for advancement. Basic manuals give information that applies to more than one rate and rating.

Rate Training Manuals are revised from time to time to bring them up to date. The recision of a Rate Training Manual is identified by a letter following the NavPers number. You can tell whether a Rate Training Manual is the latest edition by checking the NavPers number (and the letter following the number) in the most recent edition of List of Training Manuals and Correspondence Courses, NavPers 10061 (Series).

Rate Training Manuals are designed for the special purpose of helping naval personnel prepare for advancement. By this time, you have probably developed your own way of studying these manuals. Some of the personnel you train, however, may need guidance in the use of Rate Training Manuals. Although there is no single "best" way to study a training manual, the following suggestions have proved useful for many people:

1. Study the military requirements and the professional qualifications for your rate before you study the training manual, and refer to the "quals" frequently as you study. Remember, you are studying the training manual primarily to meet these "quals."

2. Before you begin to study any part of the training manual intensively, get acquainted with the entire manual. Read the preface and the table of contents. Check through the index. Thumb through the manual without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.

3. Look at the training manual in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope and content of the manual.

4. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit–it may be a chapter, a section of a chapter, or a subsection. The amount of material you can cover at one time will vary. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

5. In studying each unit, write down questions as they occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

6. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill or a situation, ask yourself some questions. Does this information tie in with past experience? Or is this something new and different? How does this information relate to the qualifications for advancement?

7. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Without looking at the training manual, write down the main ideas you have learned from studying this unit. Do not just quote the manual. If you cannot give these ideas in your own words, the chances are that you have not really mastered the information.

8. Use Enlisted Correspondence Courses whenever you can. The correspondence courses are based on Rate Training Manuals or other

appropriate texts. As mentioned before, completion of a mandatory Rate Training Manual can be accomplished by passing an Enlisted Correspondence Course based on the training manual. You will probably find it helpful to take other correspondence courses, as well as those based on mandatory training manuals. Taking a correspondence course helps you to master the information given in the training manual, and also gives you an idea of how much you have learned.

INCREASED RESPONSIBILITIES

When you assumed the duties of a PO3, you began to accept a certain amount of responsibility for the work of others. With each advancement, you accept an increasing responsibility in military matters and in matters relating to the professional work of your rate. When you advance to PO1 or CPO, you will find a noticeable increase in your responsibilities for leadership, supervision, training, working with others, and keeping up with new developments.

As your responsibilities increase, your ability to communicate clearly and effectively must also increase. The simplest and most direct means of communication is a common language. The basic requirement for effective communication is therefore a knowledge of your own language. Use correct language in speaking and in writing. Remember that the basic purpose of all communication is understanding. To lead, supervise, and train others, you must be able to speak and write in such a way that others can understand exactly what you mean.

Leadership and Supervision

As a PO1 or CPO, you will be regarded as a leader and supervisor. Both officers and enlisted personnel will expect you to translate the general orders given by officers into detailed, practical, on-the-job language that can be understood and followed by relatively inexperienced personnel. In dealing with your juniors, it is up to you to see that they perform their jobs correctly. At the same time, you must be able to explain to officers any important problems or needs of enlisted personnel. In all military and professional matters, your responsibilities will extend both upward and downward.

Along with your increased responsibilities, you will also have increased authority. Officers and petty officers have POSITIONAL authority–that is, their authority over others lies in their positions. If your CO is relieved, for example, he no longer has the degree of authority over you that he had while he was your CO, although he still retains the military authority that all seniors have over subordinates. As a PO1, you will have some degree of positional authority; as a CPO, you will have even more. When exercising your authority, remember that it is positional–it is the rate you have, rather than the person you are, that gives you this authority.

A Petty Officer conscientiously and proudly exercises his authority to carry out the responsibilities he is given. He takes a personal interest in the success of both sides of the chain of command . . . authority and responsibility. For it is true that the Petty Officer who does not seek out and accept responsibility, loses his authority and then the responsibility he thinks he deserves. He must be sure, by his example and by his instruction, that the Petty Officers under him also accept responsibility. In short, he must be the leader his title–Petty Officer–says he is.

Training

As a PO1 or CPO, you will have regular and continuing responsibilities for training others. Even if you are lucky enough to have a group of subordinates who are all highly skilled and well trained, you will still find that training is necessary. For example, you will always be responsible for training lower rated personnel for advancement. Also, some of your best workers may be transferred; and inexperienced or poorly trained personnel may be assigned to you. A particular job may call for skills that none of your personnel have. These and similar problems require that you be a training specialist–one who can conduct formal and informal training programs to qualify personnel for advancement, and one who can train individuals and groups in the effective execution of assigned tasks.

In using this training manual, study the information from two points of view. First, what do you yourself need to learn from it? And second, how would you go about teaching this information to others?

Training goes on all the time. Every time a person does a particular piece of work, some learning is taking place. As a supervisor and as a training expert, one of your biggest jobs is to see that your personnel learn the RIGHT things about each job so that they will not form bad work habits. An error that is repeated a few times is well on its way to becoming a bad habit. You will have to learn the difference between oversupervising and not supervising enough. No one can do his best work with a supervisor constantly supervising. On the other hand, you cannot turn an entire job over to an inexperienced person and expect him to do it correctly without any help or supervision.

In training lower rated personnel, emphasize the importance of learning and using correct terminology. A command of the technical languages of your occupational field enables you to receive and convey information accurately and to exchange ideas with others. A person who does not understand the precise meaning of terms used in connection with his work is definitely at a disadvantage when he tries to read official publications relating to his work. He is also at a great disadvantage when he takes the examinations for advancement. To train others in the correct use of technical terms, you will need to be very careful in your own use of words. Use correct terminology and insist that personnel you are supervising use it too.

You will find the Record of Practical Factors, NavPers 1414/1, a useful guide in planning and carrying out training programs. From this record, you can tell which practical factors have been checked off and which ones have not yet been done. Use this information to plan a training program that will fit the needs of the personnel you are training.

On-the-job training is usually controlled through daily and weekly work assignments. When you are working on a tight schedule, you will generally want to assign each person to the part of the job that you know he can do best. In the long run, however, you will gain more by assigning personnel to a variety of jobs so that each person can acquire broad experience. By giving people a chance to do carefully supervised work in areas in which they are relatively inexperienced, you will increase the range of skills of each person and thus improve the flexibility of your working group.

CROSS TRAINING. -Preparing men in service ratings for advancement to the general rating is an important part of your training job. As noted before, men in a service rating cannot advance to the general rating without first qualifying for the duties of all the service ratings included in the particular general rating.

The first step in setting up a program of cross-training is to make a careful study of the qualifications. Suppose, for instance, that you are going to train AQF2 for advancement to AQ1. First of all, you know that he will have to be trained in all areas indicated by qualifications for advancement to AQ1. In addition, you will have to make sure that he is trained in all areas of qualification required for AQB3 and AQB2.

In some cases, of course, third class and second class qualifications are common to both service ratings. For example, "test, select, and replace circuit parts" is a requirement for advancement to AQF3 and AQB3; consequently you know that AQF2 has already been checked out on this qualification. However, the qualification "perform routine preventive maintenance, preliminary troubleshooting, and minor repairs on aircraft bomb director radar" is required for advancement to AQB3 but is not required for AQF3. Therefore, the AQF2 who wants to advance must learn to perform these additional requirements.

After you have listed all the AQB3 and AQF3 qualifications that the AQF2 must now learn to meet, group these qualifications into logical units of work or study. Some of the material can be learned by study of the appropriate training manual. Other subjects can only be learned by practical experience. Whenever possible, use regular working situations as training situations. When formal training is required, plan it all out in advance so that you will be able to make the best use of the available time.

Working with Others

As you advance to PO1 or CPO, you will find that many of your plans and decisions affect a large number of people, some of whom are not even in your own occupational field. It becomes increasingly important, therefore, for you to understand the duties and the responsibilities of personnel in other ratings. Every petty officer in the Navy is a technical specialist in his own field. Learn as much as you can about the work of others, and plan your own work so that it will fit into the overall mission of the organization.

Keeping Up With New Developments

Practically everything in the Navy–policies, procedures, publications, equipment systems–

is subject to change and development. As a PO1 or CPO, you must keep yourself informed about changes and new developments that affect you or your work in any way.

Some changes will be called directly to your attention, but others will be harder to find. Try to develop a special kind of alertness for new information. When you hear about anything new in the Navy, find out whether there is any way in which it might affect your work. If so, find out more about it.

SOURCES OF INFORMATION

As a PO1 or CPO, you must have an extensive knowledge of the references to consult for accurate, authoritative, up-to-date information on all subjects related to the military and professional requirements for advancement.

Publications mentioned in this chapter are subject to change or revision from time to time–some at regular intervals, others as the need arises. When using any publication that is subject to revision, make sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made.

A list of training manuals and publications that will be helpful as references and for additional study in preparing for advancement is included in the reading list at the beginning of the text. Additional training manuals that are applicable are available through your educational services officer.

In addition to training manuals and publications, training films furnish a valuable source of supplementary information. Films that may be helpful are listed in the U. S. Navy Film catalog, NavAir 10-1-777.

ADVANCEMENT OPPORTUNITIES FOR PETTY OFFICERS

Making chief is not the end of the line as far as advancement is concerned. Proficiency pay, advancement to Senior (E-8) and Master (E-9) Chief, and advancement to Warrant Officer and Commissioned Officer are among the opportunities that are available to qualified petty officers. These special paths of advancement are open to personnel who have demonstrated outstanding professional ability, the highest order of leadership and military responsibility, and unquestionable moral integrity.

PROFICIENCY PAY

The Career Compensation Act of 1949, as amended, provides for the award of proficiency pay to designated enlisted personnel who possess special proficiency in a military skill. Proficiency pay is given in addition to regular pay and allowances and any special or incentive pay to which you are entitled. Certain enlisted personnel in pay grades E-4 through E-9 are eligible for proficiency pay. Proficiency pay is allocated by ratings and NEC's, with most awards being given in the ratings and NEC's which are designated as critical. The eligibility requirements for proficiency pay are subject to change. In general, however, you must be recommended by your commanding officer, have a certain length of time on continuous active duty, and be career designated.

ADVANCEMENT TO SENIOR AND MASTER CHIEF

Chief petty officers may qualify for the advanced grades of Senior and Master Chief which are now provided in the enlisted pay structure. These advanced grades provide for substantial increases in pay, together with increased responsibilities and additional prestige. The requirements for advancement to Senior and Master Chief are subject to change but, in general, include a certain length of time in grade, a certain length of time in the naval service, a recommendation by the commanding officer, and a sufficiently high mark on the Navy-wide examination. The final selection for Senior and Master Chief is made by a regularly convened selection board.

Examination Subjects

Qualifications for advancement to Senior Chief Petty Officer and Master Chief Petty Officer have been developed and published in the Manual of Qualifications for Advancement, NavPers 18068 (Series). They officially establish minimum military and professional qualifications for Senior and Master Petty Chief Officers.

Training Publications for Advancement, NavPers 10052 (Series) contains a list of study references which may be used to study for both military and professional requirements.

The satisfactory completion of the correspondence course titled Navy Regulations, NavPers 10740-A, is mandatory for advancement to E-8, and the course titled Military Justice in the Navy, NavPers 10993, is required of all personnel advancing to E-9.

ADVANCEMENT TO WARRANT AND COMMISSIONED OFFICER

The Warrant Officer program provides opportunity for advancement to warrant rank for E-6 and above enlisted personnel. E-6's, to be eligible, must have passed an E-7 rating exam prior to selection.

The LDO program provides a path of advancement from warrant officer to commissioned officer. LDO's are limited, as are warrants, in their duty, to the broad technical fields associated with their former rating.

If interested in becoming a warrant or commissioned officer, ask your educational services officer for the latest requirements that apply to your particular case.

CHAPTER 2

AIRCRAFT MAINTENANCE ORGANIZATION

In order to maintain increasingly complex aircraft in their prime operating condition, various aircraft maintenance organizations and procedures have been employed throughout the Navy. Prior to and during World War II, it was a general practice for every operating activity to have its own maintenance spaces, equipment, and a complement of maintenance personnel to accomplish all maintenance except overhaul. Due to variance in workload between squadrons, some shops were idle at times and could have been used by maintenance personnel from other squadrons on the same station to accomplish their work.

A combining of talents, efforts, facilities, and equipments for the accomplishment of common tasks was indicated. Through the process of evolution, combining of naval aircraft maintenance personnel and consolidation of maintenance facilities were effected on a Navy-wide basis when the Naval Aircraft Maintenance Program (NAMP) was established.

NAVAL AIRCRAFT MAINTENANCE PROGRAM

The Naval Aircraft Maintenance Program was designed to insure maximum utilization of manpower, material, and equipment and establish standard maintenance procedures and organizations for the accomplishment of maintenance on naval aircraft and associated equipment. The adoption of standard organizations and procedures promotes a high degree of uniformity among all activities in the methods that are used to manage and utilize maintenance personnel, material, and facilities. It results in a decrease in time required to indoctrinate recently assigned personnel.

The improvement of aircraft readiness is of utmost importance; costly, complex weapons systems and spares demand maximum command attention to the repair of critical items to enable aircraft to be in a ready status. It is therefore mandatory that all maintenance personnel have a thorough knowledge of and abide by the established procedures.

LEVELS OF MAINTENANCE

The task of maintaining naval aircraft in an operationally ready condition ranges from a few minutes of squadron servicing to months of overhaul in a depot level maintenance activity. To more efficiently accomplish maintenance on military aircraft the present concept is to divide the maintenance functions into three distinct levels–depot, intermediate, and organizational. The determination of what maintenance will be performed at each level is governed primarily by the availability and distribution of maintenance equipment and facilities.

Each command and support agency is responsible for continually reviewing the distribution of equipment and facilities to insure that the amount of maintenance performed at the lowest levels is consistent with available skills and personnel.

Organizational Maintenance

Organizational maintenance is the type of work performed by the operating squadron or unit on a day-to-day basis in support of its own operations. Maintenance performed at this level includes (1) inspection, (2) servicing, (3) handling, (4) "on-aircraft" corrective maintenance, including removal and installation of parts and components, (5) complying with technical directives (when prescribed), and (6) the necessary recordkeeping and reports peculiar to organizational maintenance.

Organizational maintenance in an operating activity is performed by permanently assigned personnel who are not responsible for intermediate maintenance. Organizational maintenance at shore stations (on aircraft assigned to the station) normally is a function of the Operations Maintenance Division (OMD). The OMD also provides organizational maintenance and such other assistance to transiting aircraft as may be directed by higher authority.

Intermediate Maintenance

Intermediate maintenance is that type of work performed in centrally located facilities for the support of operating activities within a designated geographical area, at a particular base or station, or aboard aviation ships. This level maintenance activities perform maintemance to such units as Station or Ships Aircraft Intermediate Maintenance Departments (AIMD), Marine Headquarters and Maintenance Squadrons, Marine Aircraft Maintenance Squadrons, etc. Typical of the work performed at this level is shop type repair and test work on aircraft components and equipment from the supported units. Technical assistance, when required, is furnished by personnel of the intermediate maintenance facility to the supported operating activities.

Intermediate maintenance activities are normally manned by a nucleus of permanently assigned personnel and certain designated intermediate maintenance personnel temporarily assigned from the on-board tenant squadrons. When these squadrons deploy from their home stations, their intermediate maintenance personnel accompany them, and are then temporarily assigned to the AIMD if afloat or at their new station.

Depot Maintenance

Depot maintenance is that type of work normally accomplished in an industrial type facility (Naval Air Rework Facilities or contractors' plants). This level includes overhaul and major repair or modification of aircraft, components, and equipments. It also includes the manufacture of specified aeronautical parts to be stocked as spares and the manufacture of kits for the accomplishment of aircraft and equipment modification. Installation of these spareparts kits may be done at this or a specific lower level of maintenance.

Navy Depot maintenance activities are manned primarily by civilians. However, some military personnel are usually assigned and assist with the intermediate and organizational type work necessarily connected with the depot facility.

It can be seen from the foregoing that the three aircraft maintenance levels or categories provide for an orderly separation of the various maintenance tasks. The bases for the separation are complexity of the task, equipment and space requirements, the skill level of assigned personnel, and the scope of support responsibility.

FUNCTIONS/RESPONSIBILITIES

Functions relate only to the maintenance level authorized to perform the task and have no bearing on the rating or skill required. Some levels will require more than one skill or rating to accomplish its task. Allowance lists for support equipment, tools, and material reflect these maintenance level assignments. The depth and complexity of the specific function will vary with the number and type of aircraft involved.

The Chief of Naval Operations assigns maintenance responsibilities to the operating forces, and the Naval Air Systems Command assigns maintenance responsibilities to the activities ashore under its control. Some activities may be assigned intermediate level maintenance responsibility for an entire logistic area if requested by the cognizant controlling custodian. Specific activities designated to perform intermediate maintenance are authorized to perform higher level maintenance on systems and equipment unique to the assigned mission, and certain other organizational level activities are authorized to perform selective functions in partial intermediate support of their own operations.

SHORE STATIONS

Navy activities ashore assigned intermediate level maintenance responsibilities establish an Aircraft Intermediate Maintenance Department, usually referred to as AIMD. Those activities with assigned aircraft establish a maintenance division within the operations department to perform organizational maintenance on assigned aircraft and on transit aircraft. Intermediate level maintenance activities perform maintenance in support of station aircraft and tenant squadrons and units. The intermediate activity also provides facilities and equipment for tenants to accomplish organizational maintenance. Tenant activities aboard shore stations furnish personnel to the intermediate activity for the accomplishments of its responsibility, and the personnel are used only in the normal spectrum of their individual rate or rating.

All Naval Reserve Training Units (NARTU's) and Naval Air Reserve Maintenance Units (NARMU's) are responsible for intermediate and organizational maintenance on their assigned aircraft; however, the supporting activity is responsible for logistic support. Naval and Marine air reserve squadrons are responsible for organizational maintenance on their assigned aircraft while on active duty or assigned to a fleet unit. During regular scheduled drill periods, maintenance is performed according to the training requirements.

SHIPS

For discussion purposes this topic includes aircraft carriers and other aviation ships (AV's, ARVA's, and ARVC's).

Aircraft Carriers

The need for establishing an Aircraft Intermediate Maintenance Department was recognized by CNO and supported by fleet commanders. Therefore, this department was established in all aircraft carriers (less the one operating with NATRACOM), assigning intermediate maintenance responsibilities afloat to the AIMD instead of the Air Wing/Group Commanders. (See fig. 2-1.) This action dissolves the V-6 division, assigning those functions not directly related to intermediate maintenance to appropriate departments. Squadron maintenance personnel will be assigned to the AIMD as previously discussed.

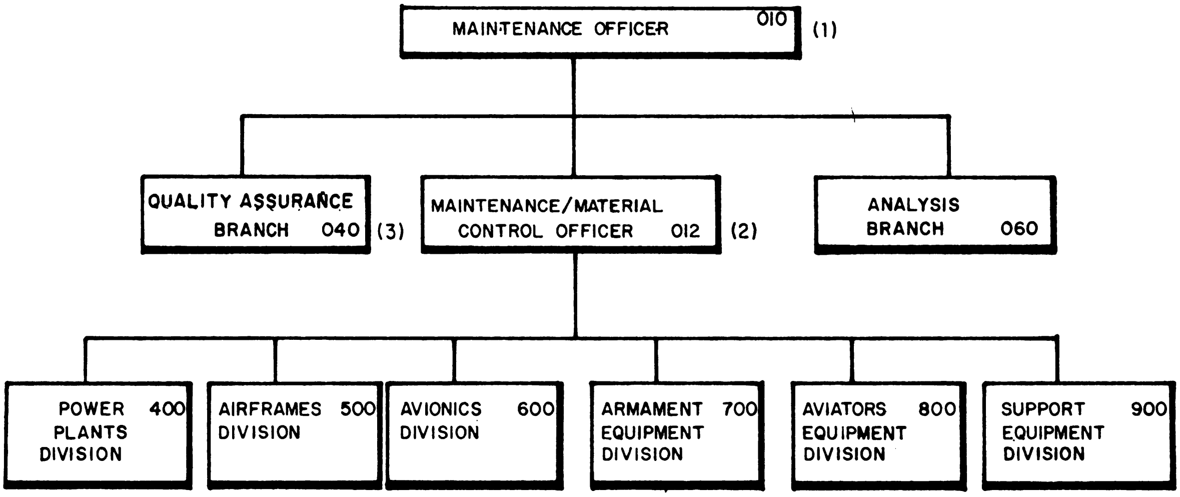
Other Aviation Ships

These ships are responsible for performance of organizational maintenance on assigned aircraft. If aircraft are operated from the ship, intermediate level maintenance facilities are provided air groups, squadrons, and units. Aircraft repair ships (ARVA/ARVC) are assigned intermediate level maintenance responsibility.

Nonaviation ships operating or tending aircraft are not assigned maintenance responsibility; however, they provide intermediate and organizational maintenance facilities, support equipment, and material for embarked units.

SQUADRONS

Navy squadrons and units are responsible for performing organizational maintenance on assigned aircraft, with the exception of VRF squadrons. The station supporting activity performs their organizational and intermediate maintenance. All squadrons are required to provide personnel for temporary assignment to the intermediate aircraft maintenance department responsible for squadron support.


MAINTENANCE OFFICER 010
(1)
QUALITY ASSURANCE BRANCH 040
(3)
MAINTENANCE/MATERIAL CONTROL OFFICER 012
(2)
ANALYSIS BRANCH 060
POWER PLANTS DIVISION 400
AIRFRAMES DIVISION 500
AVIONICS DIVISION 600
ARMAMENT EQUIPMENT DIVISION 700
AVIATORS EQUIPMENT DIVISION 800
SUPPORT EQUIPMENT DIVISION 900

NOTES:

(1) AND (2) THE AIRCRAFT MAINTENANCE DEPARTMENT OFFICER (AFLOAT), DEPENDENT UPON HIS SENIORITY, WILL BE ASSIGNED AS EITHER THE INTERMEDIATE MAINTENANCE OFFICER OR MAINTENANCE/MATERIAL CONTROL OFFICER FOR CUSTODY/CONTINUITY PURPOSE UPON DEBARKATION OF THE AIR WING.

(3) BRANCH OFFICERS WILL BE TAD FROM AIR WING/GROUP TO THE IMA FOR MANAGEMENT RESPONSIBILITIES.

AT.1

Figure 2-1.–Intermediate level maintenance activity organization, afloat.

AIRCRAFT MAINTENANCE DEPARTMENT ORGANIZATION

The organization for Aircraft Maintenance Departments provide firm lines of authority from the maintenance officer to personnel accomplishing the work for which the department is responsible. The term "department" used in this training course is used as a general term which applies fully to all maintenance activities having a department head. In cases of maintenance activities assigned as divisions to other departments, the next echelon (division) is used in place of department. Branches become sections, and sections become units.

Major segments of the department are called divisions. Divisions are subdivided into branches and branches are subdivided into sections if necessary. The aircraft maintenance officer manages the department and is responsible to the commanding officer for the accomplishment of the department's mission.

The Aircraft Maintenance Department supports naval operations by the upkeep of assigned and supported aircraft and associated support equipments to the level and depth of maintenance assigned. Specific functions include the following:

1. Periodic maintenance and routine inspection and servicing of aircraft, associated support equipment, and aeronautical material and components including the necessary disassembly, cleaning, examination, repair, modification test, inspection, assembly, and preservation.
2. Special work in compliance with technical directives or local instructions.
3. Correction of discrepancies.
4. Assurance of high quality of all work.
5. Maintenance of records and technical publications.
6. Maintenance and custody of tools and other organizational equipment.
7. Training of assigned personnel.
8. Conduct maintenance and ground handling safety programs.

INTERMEDIATE LEVEL ACTIVITY

The primary purpose of this level maintenance is to support and supplement the work of organizational maintenance activities. These functions are normally performed in centrally located areas for the support of operating aircraft on a shore station, aboard a ship, or within a designated area.

The responsibility for intermediate level maintenance is assigned to station aircraft maintenance departments ashore and aircraft intermediate maintenance departments afloat and encompasses the following:

1. Repair and test of aircraft components requiring shop facilities not available in a lower level maintenance activity.
2. Aircraft changes and modifications.
3. Reporting and keeping of records.

Figure 2-2 illustrates an intermediate level maintenance activity, including work center code numbers. As can be seen in the figure, the activity is composed of staff and production divisions.

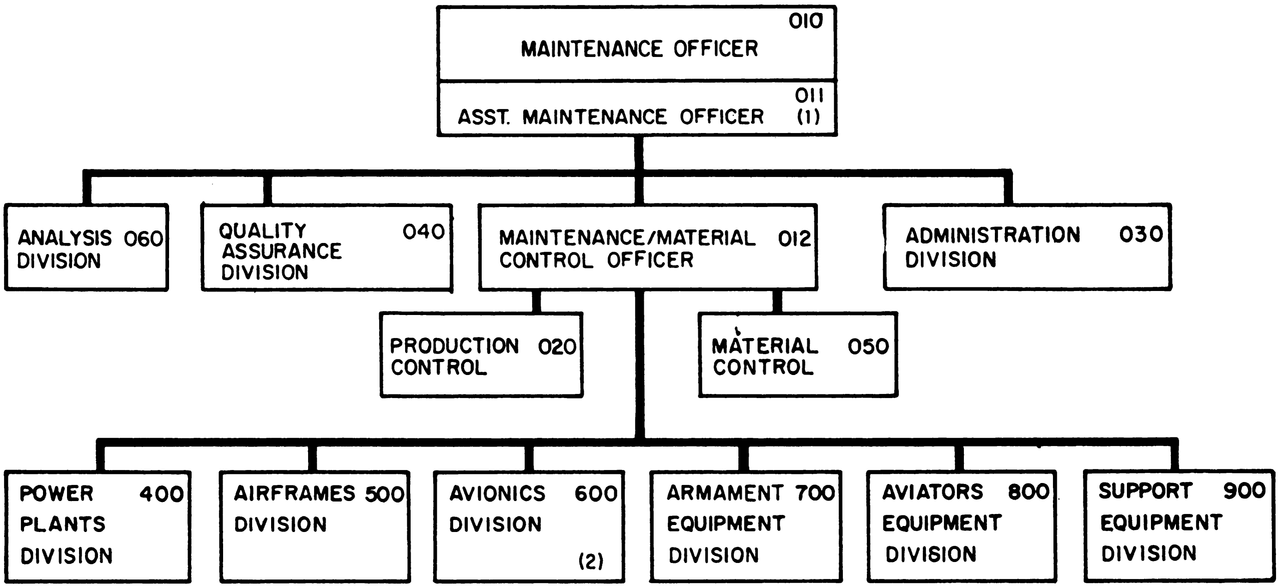
Maintenance/Material Control Officer

The Maintenance/Material Control Officer is directly responsible to the Maintenance Officer for the management of the overall productive effort of the department. His general responsibilities include but are not limited to the following:

1. Scheduling, coordinating, and monitoring the workload of the department.
2. Maintaining liaison with supported/supporting activities and the local supply department to insure material requirements are fulfilled in order to keep productive capacity compatible with workload requirements.
3. Coordinating the order, receipt, and delivery of material, the administrative screening, scheduling, and control of processed components, and the control and usage of funds provided the department.

In discharging the duties of production control, the Maintenance/Material Control Officer will perform the following:

1. Plan and schedule the workload so as to insure maximum utilization of personnel, material, and resources.
2. Coordinate the actions of the production divisions to insure prompt movement of components through the department.
3. Assign production control numbers, work priorities, due in and due out dates to the various work centers, and establish maintenance control procedures in order to effectively monitor the daily workload requirements.
4. Maintain technical directive control procedures for the department.
5. Review and approve work requests from supported activities.
6. Maintain files of completed maintenance


010
MAINTENANCE OFFICER
011
ASST. MAINTENANCE OFFICER (1)
ANALYSIS 060 DIVISION
QUALITY ASSURANCE DIVISION 040
MAINTENANCE/MATERIAL 012 CONTROL OFFICER
ADMINISTRATION 030 DIVISION
PRODUCTION 020 CONTROL
MATERIAL 050 CONTROL
POWER 400 PLANTS DIVISION
AIRFRAMES 500 DIVISION
AVIONICS 600 DIVISION (2)
ARMAMENT 700 EQUIPMENT DIVISION
AVIATORS 800 EQUIPMENT DIVISION
SUPPORT 900 EQUIPMENT DIVISION

NOTES: (1) WHEN ASSIGNED

(2) QUALIFICATION WILL BE PERFORMED BY THE TEST EQUIPMENT BRANCH OF THE AVIONICS DIVISION

AT. 2

Figure 2-2. –Intermediate maintenance activity, ashore.

action forms and work requests (6 months).

7. Maintain the Intermediate Maintenance Control Register.

8. Recommend and control cannibalization in accordance with applicable directives.

9. Submit reports as applicable.

10. Analyze daily and monthly maintenance data reports to ascertain effective utilization of personnel resources.

An assistant to the Maintenance/Material Control Officer will discharge the duties of material control by performing the following:

1. Plan, requisition, and expedite materials to enable the department to perform its mission quickly and effectively.

2. Pass all requirements for material for support of weapons system maintenance to the supporting SSC (Supply Support Center), and maintain a material control register for these items.

3. Establish delivery-pickup points for all material as mutually agreed upon by the Supply and Maintenance Officers. Insure that material received is expeditiously routed to the applicable work center.

4. Furnish technical advice and information to the supply activity on the identity and quantity of supplies, spare parts, and materials required for maintenance actions.

5. Establish procedures to insure the periodic inventory of tools and the adequate accountability of material and equipment.

6. Initiate surveys in the event of loss, damage, or destruction of accountable material.

7. Keep the Maintenance/Material Control Officer advised of the overall supply situation as it affects the department.

8. Verify Aircraft on Work Stoppage (AOWS) requisitions and prepare necessary reports in accordance with chapter IV of the 3-M Manual.

9. Perform cost and allotment record accounting, charting, and budgeting of costs applicable to the department.

10. Monitor the operation of toolrooms and maintain an updated IMRL (Individual Material Readiness List).

11. Arrange for return of prospective F condition or R/S material and locally repaired RFI material to supply.

12. Operate an administrative-screening unit in accordance with chapter IV of the 3-M Manual.

13. Retain material within the department that is in AWP status until such time the

requisition is filled and continually ascertain follow-up status on same.

Staff Divisions

Staff divisions are incorporated into the framework of aircraft maintenance activities for the purpose of providing services and support to the production divisions. A discussion of some of the more important functions of the staff divisions is contained in the following paragraphs:

ANALYSIS DIVISION. - The Analysis Division provides qualitative and quantitative analysis information to the Maintenance Officer in order to enable him to continually review the management practices within his organization by accomplishing the following functions:

1. Managing, coordinating, and monitoring the MDCS (Maintenance Data Collection System) for the department.
2. Reviewing MDR (Maintenance Data Reports) to discover and point out workload inequities, personnel inequities, and resource inequities.
3. Collecting, reviewing, and delivering source documents to data services for processing. Picking up complete data reports and disseminating throughout the organization.
4. Maintaining an adequate supply of manuals, source documents, registers, etc., on hand to insure continuity in the MDCS.
5. Developing an analytical plan which encompasses all maintenance functions to provide periodic audits of work center performance.
6. Developing charts, graphs, and displays for command presentations
7. Maintaining an updated master roster for the department.
8. Coordinating and insuring that 3-M training services are provided to assigned personnel.

ADMINISTRATION DIVISION. - The standard organization structure for intermediate maintenance activities provides an administration division. (In activities where organizational is the highest level of maintenance performed, the organization structure does not provide for a separate administration division. In such activities the functions of the administration division are the responsibility of the Assistant Aircraft Maintenance Officer.)

Administration division personnel accomplish the following specific functions:

1. Establish and control a central reporting and record keeping system for all maintenance reports and correspondence.
2. Implement all directives concerning distribution, retention, and disposition of records and reports.
3. Provide clerical and administrative services for the department.
4. Reproduce as necessary and distribute incoming messages and other data.
5. Supervise and coordinate department administrative responsibilities with other departments/divisions as required.
6. Conduct liaison with the Activity's Administration Department regarding department personnel matters.
7. Safeguard and distribute personel mail to department personnel, when appropriate.
8. Make proper distribution of all nontechnical information and publications.
9. Distribute approved locally issued maintenance instructions, reports, and studies.
10. Control classified material (excluding technical manuals and letter-type directives) required by the department.
11. Establish and coordinate the department training requirements. Obtain necessary school quotas to support these requirements.
12. Determine requirements for and insure establishment of proper transportation and communication systems to provide complete support of the workload.
13. Assign spaces to the various divisions and establish the responsibility for security and cleanliness of such spaces.
14. Assume responsibility for the cleanliness and security of vacant or unassigned aircraft maintenance spaces.
15. Arrange department participation in joint inspections of facilities assigned to tenant activities especially incident to the department of a tenant activity.

QUALITY ASSURANCE DIVISION. - The Quality Assurance Division provides the department head with the quality status of work accomplished points up areas that need particular attention, and develops more realistic inspection requirements. Primary functions performed by this division are as follows:

1. Review all incoming technical publications and directives affecting the department to determine their application to quality assurance.
2. Prepare or assist in the preparation of

maintenance instructions to insure that proper direction and emphasis is given to implementing quality assurance.

3. Maintain the master technical library for the department, including letter-type technical directives and control classified technical publications for the department. Insure that each division/branch receives all publications applicable to its work areas and that these are kept current and complete. Where applicable, maintain the Reader-Printer and associated equipment for aircraft models supported.

4. Establish qualification requirements for Quality Assurance Representatives and Collateral Duty Inspectors. Review the qualifications of personnel nominated for these positions and endorse nominations to the Commanding Officer via the department head. Maintain a current record of all designated inspectors. Periodically promulgate a list of all designated inspectors by TIMI or command notice.

5. Obtain and utilize appropriate inspection equipment such as lights, mirrors, magnifying glasses, dye penetrant kits, pressure gages, etc. Insure that productive personnel have such equipment available and in use.

6. Periodically accompany Collateral Duty Inspectors on assigned inspections and recheck their qualifications.

7. Insure all work guides, checkoff lists, checksheets, maintenance requirement cards, etc., used to define or control maintenance operations are completed and current prior to issuing to crews/individuals.

8. Review all UR entries, explanations and descriptions to insure they are accurate, clear, concise and comprehensive prior to mailing. Additionally, the technician preparing the UR and either the Quality Assurance or Maintenance Officer must sign the completed UR. Retain file copies of UR's.

9. Cause to be inspected all equipment received for use, returned for repair, or held awaiting repair to insure its material condition, identification, packaging, preservation, and configuration are satisfactory and, when applicable, that shelf life limits are not exceeded.

10. Perform inspections of maintenance equipment and precision measuring equipment to insure compliance with calibration and safety instructions.

11. Perform technical inspections of all maintenance equipment and facilities.

12. Provide for the continuous on-the-job training of all inspectors in the techniques and procedures pertaining to the conduct of inspections.

13. When directed or required, provide technical task forces to study trouble areas and submit recommendations for corrective action.

14. Maintain adequate records and data on discrepancies to enable establishment of trends with the specific objective of determining when discrepancies in any area are ascending.

15. Maintain liaison with contractor, NAESU, NavAirSysComRep's, and other available field technical services. Establish and maintain liaison with other maintenance activities and rework points in order to obtain information on ways for improving maintenance techniques, quality of workmanship and quality assurance procedures.

16. Review maintenance data reports and note unnecessary and/or recurring discrepancies requiring special action.

17. Insure that established standard procedures are observed by production personnel for conducting bench check, test, and repair of components including engines. Periodically check the performance of this work to insure the desired quality level is obtained.

18. Insure the configuration of aircraft components and support equipment is such that all essential/applicable modifications have been incorporated. This necessitates the review of appropriate records.

PRODUCTION DIVISIONS.-The standard organization for intermediate level maintenance activities provides six production divisions. These divisions perform maintenance on aircraft components and equipment for supported activities. The responsibilities and functions of these divisions are described in the following paragraphs.

Functions of Production Divisions.-Power Plants, Airframes, Avionics, Armament Equipment, and Aviator's Equipment Divisions will:

1. Perform intermediate level maintenance functions for tenant squadrons/detachments/units and station assigned aircraft.

2. Continuously review the intermediate level shop facilities for adequacy and make necessary recommendations to the Maintenance/Material Control Officer.

3. Initiate requests to Maintenance/Material Control Officer for production control numbers and material.

4. Nominate qualified individuals for designation as Collateral Duty Inspectors when required.

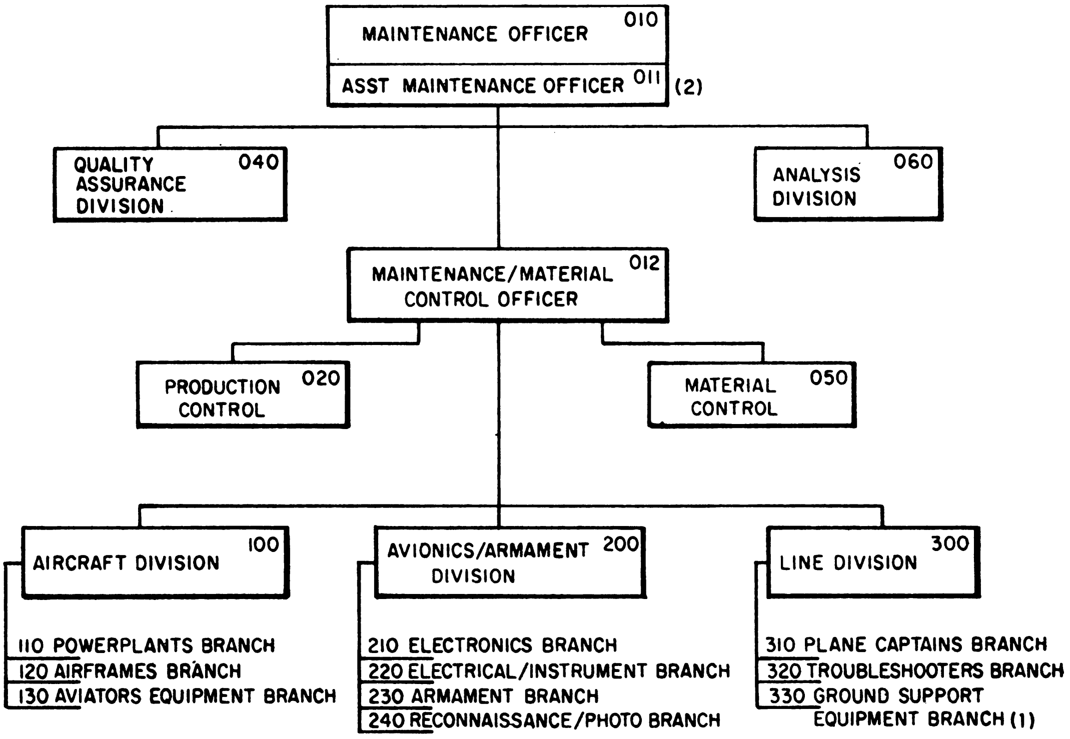
5. Maintain work center registers and master rosters.

The Support Equipment Division will:

1. Initiate action to obtain the authorized allowance of support equipment, including those items which will be subcustodied to tenants.
2. Nominate qualified individuals for designation as Collateral Duty Inspectors when required.
3. Perform intermediate maintenance on all support equipment, including repair of gas turbine powered equipment engines. Avionics support equipment will be maintained by that division.
4. Administer the program for subcustody of support equipment to other divisions of the maintenance department, Operations Maintenance Division and tenant activities. Periodically inspect subcustodied equipment, in conjunction with organizational activities, to insure proper maintenance, operation and use (except for avionics support equipment).
5. Initiate requests to Maintenance/Material Control Officer for production control numbers and material.
6. Maintain work center registers and master rosters.

ORGANIZATIONAL LEVEL ACTIVITY

The responsibility for organizational level maintenance is assigned to operating units on a day-to-day basis–to support their own operations. Maintenance performed at this level includes aircraft servicing, aircraft inspections, minor adjustments, removal and replacement of defective parts and components, limited aircraft changes and modifications, recordkeeping and reports. Figure 2-3 illustrates an


MAINTENANCE OFFICER 010
ASST MAINTENANCE OFFICER 011 (2)
QUALITY ASSURANCE DIVISION 040
ANALYSIS DIVISION 060
MAINTENANCE/MATERIAL CONTROL OFFICER 012
PRODUCTION CONTROL 020
MATERIAL CONTROL 050
AIRCRAFT DIVISION 100
AVIONICS/ARMAMENT DIVISION 200
LINE DIVISION 300
110 POWERPLANTS BRANCH
120 AIRFRAMES BRANCH
130 AVIATORS EQUIPMENT BRANCH
210 ELECTRONICS BRANCH
220 ELECTRICAL/INSTRUMENT BRANCH
230 ARMAMENT BRANCH
240 RECONNAISSANCE/PHOTO BRANCH
310 PLANE CAPTAINS BRANCH
320 TROUBLESHOOTERS BRANCH
330 GROUND SUPPORT EQUIPMENT BRANCH (1)

NOTE:

(1) When responsibilities relative to operation and maintenance of ground support equipment are extensive, the Commanding Officer will establish a Ground Support Equipment Branch under the Line Division to coordinate and/or carryout organizational maintenance functions on assigned support equipment.

(2) When assigned.

AT.3

Figure 2-3.–Organizational maintenance activity.

organizational level maintenance activity, including work center code numbers.

Maintenance/Material Control Officer

The Maintenance/Material Control Officer performs the following functions:

1. Scheduling, coordinating, and monitoring the workload of the department.
2. Maintaining liaison with the supporting activities and the local supply department to insure material requirements are fulfilled in order to keep productive capacity compatible with workload requirements.
3. Coordinating the ordering, receipt, and delivery of material, the administrative screening, scheduling, and control of processed components, and the control and usage of funds provided the department.

In discharging the duties of production control the Maintenance/Material Control Officer will:

1. Plan and schedule the workload so as to insure maximum utilization of personnel, material, and resources.
2. Assign job control numbers for each reported discrepancy.
3. Maintain the organizational maintenance control register (3 months).
4. Maintain an up-to-date status board.
5. Provide the Operations Department with required aircraft status and configuration information.
6. Maintain technical directive control procedures.
7. Relay discrepancies to work centers with complete information as to status, by the fastest method. (i.e., telephone, intercommunications, etc.)
8. Review and approve work requests to the supporting activity. (Maintain completed files.)
9. Recommend and control cannibalization in accordance with applicable directives.
10. Submit reports as required.
11. Receive certain completed source documents from work centers and:
    a. Update aircraft and equipment logs, accessory record cards, configuration forms, and associated documents.
    b. Forward complete forms to data analysis.
12. Receive complete source documents from data analysis after processing and file for historical records.
13. Conduct monthly maintenance meetings and publish a monthly maintenance plan.
14. Schedule all periodic and special inspections and insure maintenance test flights are conducted in accordance with applicable instructions.

In discharging the duties of material control, he will perform those applicable functions specified previously under intermediate level maintenance as well as the following:

1. Prepare documents for material required for operational support of weapon systems (i.e., material chargeable to BRAVO funds such as fuel, oil, and flight clothing, etc.) and material carried in SERVMART/JETMART outlets.
2. Verify NORSAIR (Not Operationally Ready Supply Aviation Item Report) requisitions and maintain (by BUNO) current NORSAIR status records.
3. Inventory aircraft upon receipt and transfer. Insure inventory logs entries are updated, authenticated and corrected.

Staff Divisions

The organizational level activity has only two staff divisions, having no administration division as explained under the intermediate level. The analysis division is the same for both activities; therefore, it is not discussed here. The quality assurance division is the same as discussed for the intermediate level with the following additions:

1. Review "yellow sheets", maintenance data reports, periodic inspection records and note unnecessary and/or recurring discrepancies that may require special action.
2. Insure that standard established practices are observed for conducting ground tests, preflight, postflight, and daily inspections. Periodically accompany check crews, plane captains, or pilots during inspection (minimum, once a quarter).
3. Insure that pilots/crew are briefed prior to each test flight so that purpose and objectives are clearly understood.
4. Maintain current the Type Commander Maintenance Index Record.

Production Divisions

The organizational level activity provides three production divisions, which are subdivided into branches. Each of these branches/divisions performs many maintenance tasks in order for the operating unit to accomplish its assigned mission.

AIRCRAFT DIVISION.—The Aircraft Division is responsible for the accomplishment of the following functions:

1. Supervise, coordinate, and complete periodic maintenance and inspections. (Check crew leaders and such other personnel authorized by the Maintenance Officer will be permanently assigned.) Additional personnel required to perform periodic maintenance and inspections will be made available as required from other production divisions. The Maintenance/Material Control Officer is responsible for insuring that divisions assign qualified personnel for the completion of scheduled maintenance and inspections.
2. As directed by the Maintenance Officer and in conjunction with other production divisions, perform those applicable organizational maintenance functions in those areas relative to assigned branches; i.e., Airframes, Power Plants and Aviators Equipment.
3. Continuously advise the Maintenance/Material Control Officer of the status of work in progress.
4. Insure cleanliness of assigned spaces.
5. Nominate personnel for assignment as collateral duty inspectors.
6. Initiate requests for maintenance material.
7. Assume custody for tools and support equipment assigned to the Aircraft Division.
8. Interpret applicable directives and prepare, in draft form, maintenance instructions to implement such directives.
9. Recommend changes in techniques to promote maximum ground safety, safety of flight, and operational readiness of aircraft.
10. Carry out an active program for FOD (foreign object damage) control, as established by the Line Division Officer.
11. Initiate requests to maintenance/material control for job control numbers.
12. Provide troubleshooters and aircrew members, as required, and exercise technical supervision over such personnel.
13. Expedite the accomplishment of assigned work through the continuous evaluation of methods and procedures, and incorporate new techniques as appropriate.

AVIONICS/ARMAMENT DIVISION.—The Avionics/Armament Division is responsible for the accomplishment of the following functions:

1. Assign personnel required to accomplish scheduled periodic maintenance and inspections of assigned aircraft. (The Aircraft Division is responsible for the supervision, coordination, and completion of periodic maintenance and inspections.)
2. As directed by the Maintenance Officer and in conjunction with other production divisions, perform maintenance functions in those areas relative to assigned branches, i.e., Electronics, Electrical/Instrument, Armament and Reconnaissance/Photographic.
3. Advise the Maintenance/Material Control Officer of the status of work in progress.
4. Insure cleanliness of assigned spaces.
5. Assume custody and accountability for assigned tools and support equipment.
6. Initiate requests for maintenance material.
7. Nominate qualified individuals for assignment as collateral duty inspectors.
8. Interpret applicable directives and prepare, in draft form, maintenance instructions to implement such directives.
9. Recommend changes in methods and techniques to promote maximum ground safety, safety of flight, and operational readiness of aircraft.
10. Initiate requests to maintenance/material control for job control numbers.
11. Provide troubleshooters and aircrew members, as required, and exercise technical supervision over such personnel.
12. Expedite the accomplishment of assigned work by continuous evaluation of methods and procedures and incorporate new techniques.

LINE DIVISION.—The Line Division is responsible for the accomplishment of the following functions:

1. Assign personnel, as required, to accomplish periodic maintenance and inspections of assigned aircraft. (The Aircraft Division is responsible for the supervision, coordination, and completion of periodic maintenance and inspections.)
2. As directed by the Maintenance Officer and in conjunction with other production divisions, perform those applicable organizational maintenance functions in those areas relative to assigned branches; i.e., plane captains, troubleshooters, and ground support equipment (when established).
3. Coordination and direction of troubleshooters. Although troubleshooters will normally be assigned from other divisions on a daily basis, the Maintenance Officer may assign personnel permanently to a Troubleshooter Branch of the Line Division. A troubleshooter should accomplish correction of minor

discrepancies.

4. Initiate requests to maintenance/material for job control numbers.
5. Provide to pilots/aircrews records of aircraft discrepancies and corrective actions for the preceding 10 flights of the aircraft.
6. Administer the plane captain program.
7. Nominate qualified personnel as collateral duty inspectors.
8. Participate in an active FOD (Foreign object damage) prevention program.
9. Initiate requests for maintenance material.
10. Insure the cleanliness of assigned aircraft and spaces.
11. Assume custody and accountability for tools and aircraft maintenance support equipment assigned to the division/branch.
12. Insure the security and proper ground handling of aircraft and associated support equipment.
13. Recommend changes in methods and techniques to promote maximum ground safety, safety of flight, and operational readiness of assigned aircraft and associated support equipment.

NAVY MAINTENANCE AND MATERIAL MANAGEMENT (3-M) SYSTEM

The 3-M system is a program to insure the highest state of aircraft readiness and reliability at the lowest cost in men, money, and material. In accomplishing this, it must insure that maintenance personnel, equipment, and facilities are utilized to the fullest extent in the performance of maintenance and not wasted in other functions not requiring highly trained maintenance skills nor specialized and expensive maintenance equipment and facilities.

All aircraft weapon systems must be maintained to the maximum extent possible to perform 100 percent of the functions for which they were designed and to accomplish the assigned mission. Anything short of this goal is considered a compromise to readiness which cannot be afforded.

By analyzing maintenance costs and devising techniques to reduce cost wherever and whenever possible, many procedures and unnecessary actions can be minimized or eliminated entirely. Therefore, by doing away with the unnecessary, effort can be concentrated on increased readiness. The 3-M system embraces two broad areas–a Planned Maintenance System, and a Maintenance Data Collection System.

PLANNED MAINTENANCE SYSTEM

The Planned Maintenance System (PMS) is a system of maintenance planning and control that provides for the uniform accomplishment of planned preventive, rather than corrective, maintenance in all aircraft squadrons. A set of Maintenance Requirement Cards (MRC's) is provided for each type of aircraft, based on information in the Periodic Maintenance Requirements Manual (PMRM). The MRC's tell what inspections are to be performed, when and how they are to be performed, the skills, tools and equipment needed, the safety precautions to be observed, and the inspection sequence.

Many separate but interrelated functions and tasks combine to make up the maintenance workload that is required for support of modern aircraft. The times allocated and available for the accomplishment of this maintenance does not allow for all of these tasks to be considered, planned, and performed on an individual basis; therefore, it is necessary that they be combined, sequenced, and phased in the proper order if the overall task is to be accomplished in the most efficient manner. The best possible use of allocated time, manpower, materials, and funds is mandatory if the maximum potential weapons system availability and utilization are to be realized.

Operating aircraft are subject to a variety of stresses, strains, vibrations, and environments. If not inspected regularly for all defects, the aircraft would soon become inoperable. The correcting of discrepancies and timely lubrication are performed in conjunction with inspections and enable the aircraft to be flown safely until the next inspection.

The most frequent types of inspections which are performed by activities responsible for the maintenance of naval aircraft are described in the following paragraphs.

Daily Inspections

Daily inspections are accomplished between the last flight of the day and the next scheduled flight, if no more than 72 hours elapse between the inspection and the next scheduled flight. If more than 72 hours elapse between the inspection and the next flight, the inspection must be repeated. This inspection is basically a combination of requirements for checking equipment that requires a daily verification of satisfactory functioning, plus requirements that prescribe searching for and correction of relatively minor problems to prevent their progress to a state that would require major work to remedy. Other items which require inspection at intervals more frequent than prescribed for calendar inspections are also included on the daily inspection and are accomplished along with the daily inspection on the day they become due.

Preflight Inspection

A preflight inspection is performed prior to each flight. This inspection consists of checking the aircraft for flight readiness by performing visual examinations and operational tests to discover defects and maladjustments that, if not corrected, would cause accidents or aborted missions. It also includes a check to determine that the aircraft has been properly serviced for the next flight.

Postflight Inspection

A postflight inspection is performed on aircraft at the termination of the flight. This inspection includes the following:

1. Inspecting critical areas of the aircraft for obvious damage.
2. Servicing the aircraft with fuel, oil, oxygen, etc., to help maintain the aircraft in a ready-for-flight condition.
3. Installing of safety devices such as ejection seats and canopy safety pins, landing gear safety pins, and jury struts to maintain the aircraft in a safe condition.
4. Securing the aircraft after the last flight of the day. This includes installing all protective covers and plugs such as intake and exhaust covers, refrigeration and pressurization plugs, pitot covers, static vent plugs, etc.

NOTE: This inspection is no longer accomplished except where locally authorized to satisfy specific requirements.

Calendar Inspection

The calendar inspection is a thorough and searching inspection of the aircraft. It consists of visual and operational checks of sufficient depth to uncover discrepancies or progressive deterioration within the aircraft that could affect safety of mission accomplishment. This type of inspection is divided into two categories—an ODD calendar and an EVEN calendar inspection—and consists of basic requirements plus additional items scheduled for compliance at less frequent intervals.

Most of the items to be inspected at less frequent intervals are divided evenly so that approximately half of the items are checked on the first (ODD) calendar inspection and the remainder are checked at the second (EVEN) inspection. Subsequent inspections repeat the same ODD-EVEN cycle.

Under this system, the appropriate inspection is conducted at the expiration of a specified number of calendar weeks. Figure 2-4 illustrates a squadron inspection interval.

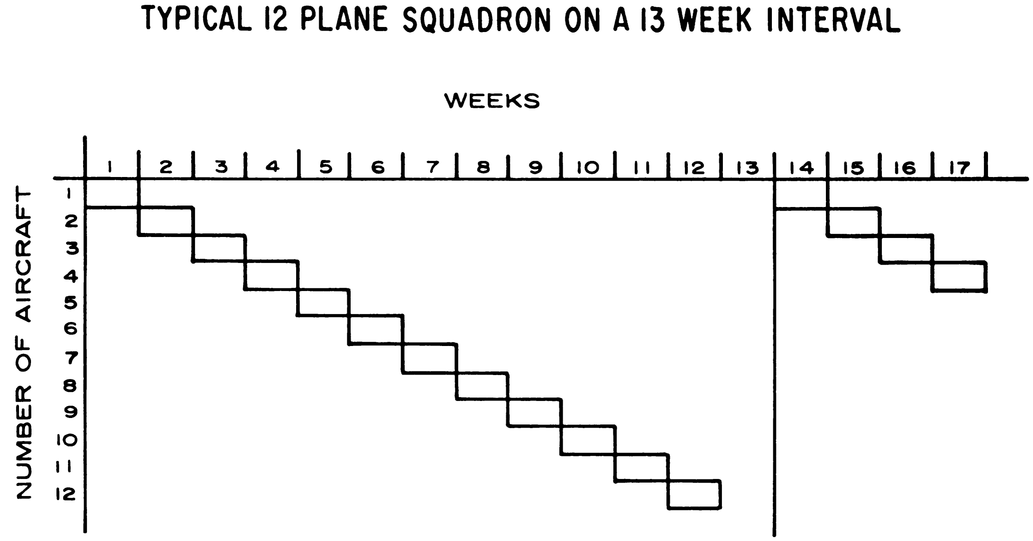
The Calendar Inspection System is an efficient system from a maintenance management standpoint. When aircraft are inspected under this system, the workload planning operation is simplified and the schedule maintenance in process is automatically stabilized.

The first inspection interval subsequent to Navy acceptance of a new aircraft under this inspection system commences on the date or at the time of the acceptance test flight. The first calendar inspection is performed at the completion of this first interval with subsequent inspections performed in sequence as previously mentioned.

The first inspection interval subsequent to standard rework commences on the date entered in the Aircraft Logbook by the rework activity certifying accomplishment of the equivalent calendar inspection. The next calendar inspection due is performed at the completion of this first interval and subsequent inspections are in sequence.

During special rework, the rework activity accomplishes all inspections falling due while the aircraft is in custody of the rework activity. Calendar inspections subsequent to special rework, therefore, continue in sequence. All calendar inspections accomplished by rework are noted in the Aircraft Logbook and the Aeronautical Equipment Service Record.

CALENDAR INSPECTION PROCEDURES.—Aircraft are inspected on the calendar interval established by current NavAir Instructions or on an adjusted interval as specified by the controlling custodian. Normally, calendar inspections are programmed in multiples of calendar weeks, computed from induction date to induction date, irrespective of days consumed performing the individual inspection. Therefore, an aircraft assigned a 17-week interval would be inducted



AT. 4

Figure 2-4. –Squadron inspection interval.

into the next calendar inspection 17 weeks after the original induction day of the week.

The Calendar Inspection System is placed into operation by dividing the number of aircraft in the aircraft allowance into the calendar inspection interval (for example, 13, 17, 21, or 22 weeks) and programming scheduled maintenance and inspection requirements accordingly. Activities responsible for the maintenance and upkeep of large numbers of aircraft group them into multiple units for programming purposes.

To meet unusual situations, a plus or minus 1 week, or portion thereof, may be applied to the authorized calendar inspection interval. To enable a ferry flight to the home ship or station after an away-from-home grounding discrepancy of such duration that the calendar interval expired, necessary additional days may be added. However, in each instance each deviation must be approved by the commanding officer or officer in charge, not delegated, and applies only to the immediate inspection due. If unusual circumstances dictate deviations of succeeding calendar inspections, each is computed from the date on which the inspection would have been due if the preceding deviation had not been granted.

To eliminate peaks and valleys in the workload, the overall pattern of inspections of all aircraft should be one of alternating odd calendars and even calendars. Induction of new and reworked aircraft into an established calendar inspection schedule may require repeating or performing an otherwise unnecessary inspection to insure that the scheduled workload pattern remains one of alternating types of inspections. Newly received aircraft are required to be firmly established in the calendar inspection schedule within a period not to exceed one inspection interval.

Reporting custodians (operating activities) are authorized under current instructions to increase the depth of any inspection but not to decrease it. Whenever the depth of an inspection is increased to meet unusual or special circumstances, the inspection is recorded only as the type which was due in accordance with the programed sequence. Special inspections to an appropriate depth may be ordered by the reporting custodian whenever excessive utilization during the operating interval is considered to have impaired the material reliability or integrity of the aircraft. Such inspections are in addition to programed requirements and in no way affect the requirement for the accomplishment of the next regularly scheduled inspection.

Special instructions specified in the applicable PMRM are performed concurrently with scheduled calendar inspections when the time authorized for the special inspection is not exceeded. When the time interval will be exceeded during the calendar period inspection interval, the special inspection is accomplished as part of the scheduled daily inspection falling nearest to the requirement.

Scheduled replacement of components with stated operating limitations is normally accomplished during the calendar inspection falling nearest the hourly limitation. To facilitate maximum replacement in accordance with the foregoing, a plus or minus 10 percent of the stated operating time is permissible. When the hourly limitation plus or minus 10 percent does not coincide with a calendar inspection, the replacement is usually accomplished during the scheduled daily inspection nearest the hourly limitation.

NOTE: The Component Removal/Replacement Schedule, found in the applicable PMRM, contains a list of components which must be removed and replaced periodically. This section of the PMRM contains the nomenclature, part number or stock number, quantity, technical justification for removal, corrective action required, and replacement schedule of the components which must be replaced.

MAINTENANCE DATA COLLECTION SYSTEM(MDCS)

The Maintenance Data Collection System (MDCS) is a system for collecting, processing, and analyzing maintenance and material data and distributing information to line commanders and material commands to enable them to carry out management functions in support of the operating forces. This system is also referred to as the management system. The primary purpose of this system is to insure that basic data generated by maintenance personnel are recorded only once. This system provides information from the following categories: manhour accounting, maintenance data reporting, and aircraft statistical data.

Manhour Accounting

The effective use of available manpower is an important function of maintenance management. Manhour accounting is an important part of the MDCS. The purpose of collecting manhour data is to provide management with essential information necessary to more efficiently plan and direct the distribution of assigned personnel.

The Manhour Accounting System is based upon the "exception" principle; that is, only the deviations or exceptions from normal are reported. Through the use of master rosters, electric accounting machine cards, and machine processed reports, the system provides summaries of the hours expended by maintenance personnel during the normal working day or in an overtime status. Basically, the system is designed so that the normal working hours for each person assigned to the maintenance activity are allotted or assigned to work centers by types of labor at the beginning of each reporting period. Exceptions from these normal working hours, or labor types, are reported by use of Manhour Accounting Cards. Data processing machines add or subtract the exceptions reported on the Manhour Accounting Cards from the initial manhour allotment. These exceptions and the working hours allotted at the beginning of the period serve as the basis for the daily and monthly manhour accounting reports mentioned in the foregoing. These reports are forwarded to the maintenance officers and supervisors for validation and utilization. Each supervisor and worker must thoroughly understand the importance of the system, its operation, and the need for continual accuracy.

At the beginning of each reporting period, generally the first of the calendar month, manhours are assigned to every work center to which personnel are assigned. These manhours are based on an 8-hour workday 5 days per week for every person assigned. Not included in these "original assigned manhours" are any hours for work on Saturdays, Sundays, or holidays during the month. If every person assigned to the work center could be continuously employed throughout the month during all the time available for work, there would be no need for manhour reporting, as the time would be accounted for on the various maintenance data collection forms. Since continuous employment is not possible, each worker must report what he did when he was not working during any period in excess of 20 minutes, or approximately three-tenths of an hour.

Maintenance Data Reporting

This category of data embraces the widest range and most complex types of information involved in the Aviation 3-M System. The scope of the data collected is indicated by the descriptive titles of the data collection forms which are used. These data collection forms are commonly called "source documents." These source documents include the Support Action Form (SAF), Maintenance Action Form (MAF) (single and multicopy), Technical Directives Compliance Form (TDCF), and Configuration Control Form (CCF).

Most of these source documents are originated and completed by the production divisions; however, maintenance control personnel assist in the preparation of some of them.

The Maintenance Data Reporting (MDR) system is designed so that each worker, when accomplishing a job, converts a narrative description of the job into codes and enters the coded information on standard source documents. These source documents are collected and forwarded to the data services activity where the information is transferred onto Electric Accounting Machine (EAM) cards. Data services then uses these EAM cards to produce periodic machine reports listing and summarizing the submitted data. These reports are supplied to maintenance supervisors to provide assistance in planning and directing the maintenance effort. In addition, the information on the EAM cards is forwarded to the Central Data Processing Facility which provides data to satisfy the management requirements of type commanders, system commands, and other managers.

The MDR system provides a valuable tool for use by maintenance managers. It was not designed to replace management or supervision. It was designed to assist management, and to achieve this purpose requires strict attention from the worker to the commanding officer. As with the entire MDCS, the key to an effective MDR system is the work center supervisor. This supervisor must understand the system, the proper procedures for using the source documents and registers, and the information he collects from the machine reports. He must assure complete and accurate documentation and also insure that assigned personnel have received proper training and motivation. It is well to remember that a product from MDR is only as good as the input information, and the input is used to provide management products for the highest levels of Navy management.

Aircraft Statistical Data

Management control of an operating unit is furnished inventory, flight, and readiness information by this system. Selected information for each aircraft in the inventory of a reporting custodian is prepared and forwarded to Data Services, and this information is used to establish an accurate master file of inventory data within the local Data Services activity. When the master file is established, it is kept current by the submission of Equipment Statistical Data (ESD) Cards, which are the source documents for this system. Figure 2-5 illustrates the Equipment Statistical Data Card reporting flight data. An ESD card is utilized to report inventory information when an aircraft is gained or lost and when there is a change in the reporting status of the aircraft.

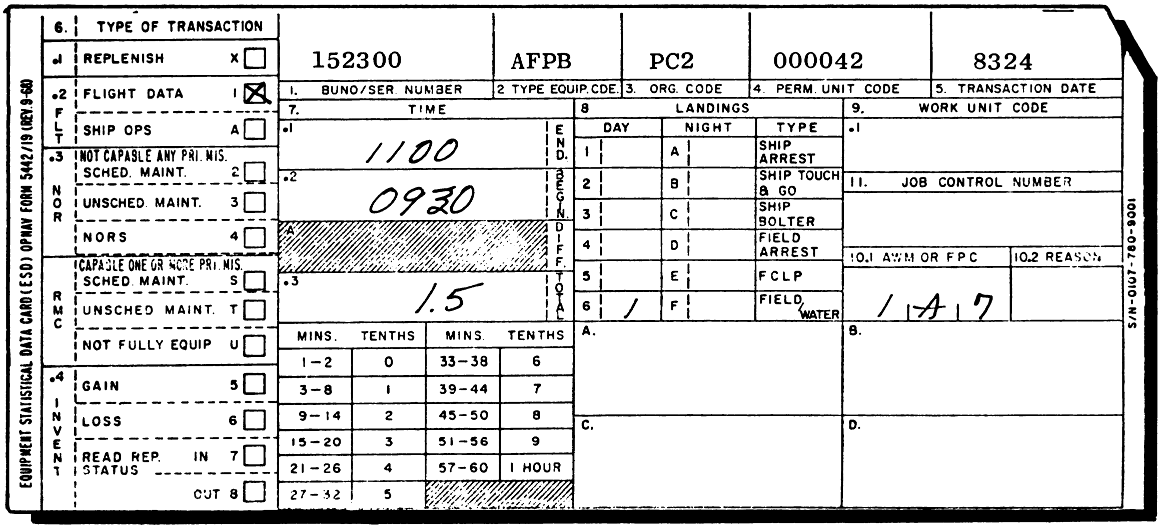
Data Services provides various reports containing inventory, readiness, and flight data. Compilation of selected elements or data in a specified format will aid in the preparation of maintenance information and will allow similar type organizations to compare statistics and equipment.

The following paragraphs provide the description of the report to be made.

The Aircraft Master List, ASD-00, is a monthly report reflecting the true inventory condition of assigned aircraft as of 0001 hours the first day of each month. The report lists the permanent unit code, type equipment code, and the assigned aircraft hours for the appropriate NOR (Not Operationally Ready) reporting status for each aircraft. This report provides a means of verifying and/or correcting data contained in the local inventory data bank.

The report is checked for accuracy and completeness using local records of aircraft inventory change transactions which occurred during the previous month. Erroneous or incomplete data should be corrected and the local inventory data bank corrected in accordance with locally established procedures.

The Daily Flight Report, ASD-1, is a detailed listing of all aircraft flight data submitted on ESD cards during the previous working day. The report may contain data for more than 1 day due to extended flights or flights on weekends or holidays. It indicates flight data collected



EQUIPMENT STATISTICAL DATA CARD (ESD) OPNAV FORM 5442/19 (REV.9-68)

6. TYPE OF TRANSACTION
- .1 REPLENISH X ☐
- .2 FLT FLIGHT DATA 1 ☒
  - SHIP OPS A ☐
- .3 NOR NOT CAPABLE ANY PRI. MIS.
  - SCHED. MAINT. 2 ☐
  - UNSCHED. MAINT. 3 ☐
  - NORS 4 ☐
- RMC CAPABLE ONE OR MORE PRI. MIS.
  - SCHED. MAINT. S ☐
  - UNSCHED. MAINT. T ☐
  - NOT FULLY EQUIP U ☐
- .4 INVENT
  - GAIN 5 ☐
  - LOSS 6 ☐
  - READ REP. STATUS IN 7 ☐
  - OUT 8 ☐

1. BUNO/SER. NUMBER	2 TYPE EQUIP. CDE.	3. ORG. CODE	4. PERM. UNIT CODE	5. TRANSACTION DATE
152300	AFPB	PC2	000042	8324

7. TIME
- .1 END. 1100
- .2 BEGIN. 0930
- A DIFF.
- .3 TOTAL 1.5

MINS.	TENTHS	MINS.	TENTHS
1-2	0	33-38	6
3-8	1	39-44	7
9-14	2	45-50	8
15-20	3	51-56	9
21-26	4	57-60	1 HOUR
27-32	5		

8 LANDINGS

DAY		NIGHT		TYPE
1		A		SHIP ARREST
2		B		SHIP TOUCH & GO
3		C		SHIP BOLTER
4		D		FIELD ARREST
5		E		FCLP
6	/	F		FIELD/WATER

9. WORK UNIT CODE
.1

11. JOB CONTROL NUMBER

10.1 AWM OR FPC	10.2 REASON
1 A 7	

A.

B.

C.

D.

S/N-0107-780-9001

Figure 2-5.—ESD Card (flight data). AQ.1

during shipboard operations and shows landing data, departure and arrival times, date, and the duration and purpose of each flight conducted by each aircraft.

This report provides a means of verifying and correcting information in Data Services files. It also provides maintenance managers with a means of monitoring aircraft utilization on a daily basis and can be used as a measure of accomplishment of the previous day's schedule. The report is checked daily for accuracy and completeness by maintenance control personnel. Erroneous entries should be lined out and the correct data inserted, in red, directly above the lined out entry. After correction the report is forwarded to the Data Services Activity.

The Daily Aircraft Readiness Report, ASD-2, is a detailed listing of all aircraft NOR and inventory data submitted on ESD cards during the previous working day. Like the ASD-1, it may contain data for more than 1 day. The ASD-2 shows not ready conditions and inventory changes by bureau number. When an aircraft is reported as NOR more than once during the same day, the data for this aircraft is listed in the order the NOR times began.

This report provides a means of verifying and correcting information in Data Services files. It also provides maintenance managers with a means of monitoring operational readiness on a daily basis.

Maintenance managers use this report to identify specific problem areas that degrade the overall readiness condition. The nature of the problem areas identified may determine what action is necessary to improve readiness. Further, this report provides the means of identifying specific aircraft that detract from overall readiness, measuring the impact of scheduled maintenance, unscheduled maintenance, and supply support on readiness, identifying potential ready hours lost to the awaiting maintenance category, identifying systems or components that contribute to NOR conditions, and computing cumulative readiness rates. The report is checked daily for accuracy and completeness, and any erroneous data corrected in the same manner as the ASD-1.

The Monthly Aircraft Readiness and Flight Report, ASD-3, is a summary of all flight and NOR ESD cards submitted during the reporting period. It shows a summation, by bureau number and type equipment, of hours assigned "IN" or "OUT" of a NOR reporting status, NOR hours by category, total flights and flight hours, and flights and flight hours during shipboard operations.

The report aids maintenance managers in their efforts to maintain optimum aircraft readiness and utilization. The format used lends itself to quick analysis of factors that affect aircraft readiness and utilization. This report provides a means to identify the operationally ready rate, not ready hours by reason, awaiting maintenance hours, aircraft lost to an "OUT" of a NOR reporting status, aircraft that continually account for a large portion of NOR hours, the hours flown by each aircraft, the average flight duration, and flights and hours accumulated during shipboard operations.

NOTE: An aircraft is "IN" a NOR reporting status when the status code of the aircraft is A1 through A8, AJ, and AK: B1 through B8, BJ, and BK: and C1 through C8, CJ, and CK. Not Operationally Ready reporting is required only on aircraft "IN" a NOR reporting status. An aircraft is "OUT" of NOR reporting status when the status code of the aircraft is other than listed above. Aircraft are not reported as NOR when "OUT" of a NOR reporting status.

In addition to these standard reports, Reporting Custodians may request special reports from data services. It should be remembered that any information known to exist in ASD files can be obtained in the form of special reports. However, if the information desired is already available in another report, a special report should not be requested. Special reports should not be used indiscriminately because of the additional, and often excessive workload imposed on Data Services personnel and machines.

MAINTENANCE FORMS AND RECORDS

Effective accomplishment of aircraft maintenance requires thorough familiarity with numerous maintenance forms and records. Some of these are discussed in other chapters of this text. Those discussed in the following paragraphs are aircraft status boards and test flight forms used in postmaintenance flight tests.

AIRCRAFT STATUS BOARD

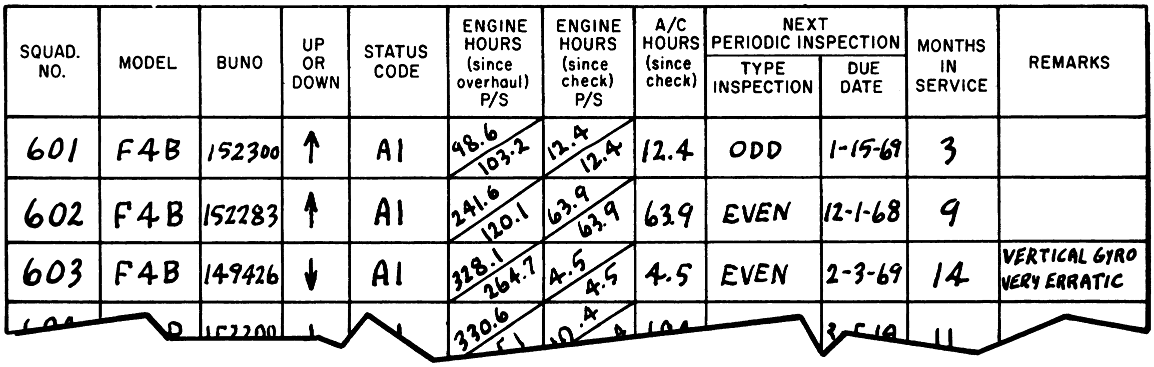
This board is maintained to provide a visual presentation of current status information on all aircraft assigned to an activity. The aircraft status board, such as the one depicted in figure 2-6, should be of suitable size and material to display sufficient information so that interested personnel can quickly ascertain the essential facts.

The size and location of the board will vary with the employment and operating conditions of the particular activity; however, it remains the responsibility of the maintenance control office to maintain the board in a current and up to date status. Additional columns and subcolumns for rapid reference may be employed to indicate the status of selected components and functional systems as well as replacement times or dates on selected items. When items which have established replacement intervals are selected for the status board, the time at which replacement is required can be effectively displayed by entering in the component column the replacement interval (or the time remaining on the item) plus the aircraft or engine time when the item was installed. Thus, replacement is required when the aircraft or engine time equals the time entered in the component column. For a more effective display, the figure in the component column may be entered in red as the replacement time or date approaches.

POST MAINTENANCE FLIGHT TESTS

The control and accomplishment of test flights may be a necessary and integral part of a maintenance process. Test flights are those flights performed to determine if the airframe,

AIRCRAFT STATUS BOARD (SAMPLE)



SQUAD. NO.	MODEL	BUNO	UP OR DOWN	STATUS CODE	ENGINE HOURS (since overhaul) P/S	ENGINE HOURS (since check) P/S	A/C HOURS (since check)	NEXT PERIODIC INSPECTION		MONTHS IN SERVICE	REMARKS
								TYPE INSPECTION	DUE DATE		
601	F4B	152300	↑	A1	98.6 103.2	12.4 12.4	12.4	ODD	1-15-69	3	
602	F4B	152283	↑	A1	241.6 120.1	63.9 63.9	63.9	EVEN	12-1-68	9	
603	F4B	149426	↓	A1	328.1 264.7	4.5 4.5	4.5	EVEN	2-3-69	14	VERTICAL GYRO VERY ERRATIC
					330.6						

AQ. 2

Figure 2-6. –Aircraft status board.

powerplant, accessories, and items of equipage are functioning in accordance with predetermined requirements while subjected to the intended operating environment. Such flights are conducted when it is not feasible or possible to determine safe and/or required functioning by means of ground or shop tests. (Refer to NavAir Instruction 4700.2 (latest series) for a listing of conditions that require flight tests.)

LOGS AND RECORDS

All activities which have reporting custody of Navy or Marine Corps aircraft have the responsibility to maintain the Aircraft Logbook and associated records for their assigned aircraft in a proper and up-to-date status.

The actual responsibility for the maintenance of the Aircraft Logbook and its associated records have been recently assigned to the Aviation Maintenance Administrationman (AZ) rating. However, since the technician must supply information for many of the entries which are made in the Aircraft Logbook, it is necessary that he be familiar with it.

AIRCRAFT LOGBOOK

The Aircraft Logbook is the record in which all data concerning the aircraft are posted. Information gathered in this log is used to determine the aircraft condition for planning its rework. Accident investigating boards determine the compliance with directives from it. It reflects a history of all significant events occurring to the airframe, its components, and accessories. It is a legal document of investigations.

NOTE: The Aircraft Logbook has recently been revised and the NavWeps 13090 forms are being replaced by NavAir forms. Some of the old forms will continue to be used until present stocks are depleted.

The Aircraft Logbook is a hard cover, looseleaf ring binder containing separators and page insert forms. Each separator and page insert is a NavAir form and is identified by individual slash numbers.

AERONAUTICAL EQUIPMENT SERVICE RECORD

The Aeronautical Equipment Service Record is a nine-part, looseleaf log contained within a separate cover and punched for insertion in the Aircraft Logbook ring binder. This record is prescribed for use with aircraft powerplants, propellers, and airborne auxiliary powerplants. When used as a propeller log, it is prepared using the propeller hub as the basic equipment and must accompany the hub throughout its service life.

The Aeronautical Equipment Service Record is initiated by the activity originally accepting the equipment for the Navy. This record is subsequently maintained by the activity having custody of the equipment. Maintenance of this record is similar to that required for the Aircraft Logbook. Although the record is maintained in the Maintenance Control Office, much of the information that must be incorporated comes from the individual shops. General familiarity with the contents of the log and the record by chief and first class petty officers in all aviation ratings is a valuable aid in the development of the spirit of cooperation so vital to the over-all maintenance effort.

The Aeronautical Equipment Service Record consists of the following:

1. The cover (NavAir Form 13090/20).
2. Part I–Guarantee Information and Basic Information (NavAir Form 13090/21A). This part contains information similar to that contained in the first two sections of the Aircraft Logbook.
3. Part II–Custody and Transfer Record.
4. Part III–Equipment Operating Log. This form is generally self-explanatory; however a few remarks may be helpful as an aid in preparation and maintenance. For instance, it should be remembered that "Military" time refers to reciprocating engines and "Afterburner" time refers to gas turbine engines. The form provides for logging of equipment operating time on a preflight, daily, weekly, or monthly basis except that ferry and test flight times are logged separately. This form provides an additional column without a heading which may be used for logging any special information.
5. Part IV–Inspection Record. The discussion of this form in the section on Aircraft Logbook also applies to the preparation and maintenance of the form when used as Part IV of the Aeronautical Equipment Service Record.
6. Part V–Record of Rework. This is also a dual usage form and is to be maintained in accordance with those instructions which apply to the Aircraft Logbook.
7. Part VI–Technical Directives. The recording of technical directives in the Aeronautical Equipment Service Record is largely

limited to "bulletin" type publications. Separate pages are used for each type directive and all applicable directives are recorded.

8. Part VII–Preservation-Depreservation Record. This part of the Aeronautical Equipment Service Record is another of the forms that is also used in the Aircraft Logbook. The purpose and the maintenance of this form when used as part of this record are basically the same as for the Aircraft Logbook.

9. Part VIII–Miscellaneous. Part VIII is used in the Aeronautical Equipment Service Record for recording pertinent information for which no other place has been provided. Such information includes special test data, abnormal characteristics of equipment, significant damage and/or repair, and authorization for extension of operating intervals.

10. Part IX–Replacement of Assemblies, Accessories, and Major Components. Part IX is another of the forms that is also used in the Aircraft Logbook. This part of the record is screened for information and discarded at time of rework, and a new Part IX is initiated.

AIRCRAFT INVENTORY

In order to maintain an unbroken chain of custodial responsibility incident to the transfer and acceptance of naval aircraft, the Standard Inventory Log was developed to be used as an instrument of transfer. In the interest of standardization among the Armed Services, the Aircraft Inventory Record has been designed by the Department of Defense for this purpose. Records are being prepared, instead of Logs, for future new production aircraft.

With remote exceptions, no aircraft may now be transferred or accepted without an Inventory Log or Record. On these occasions an inventory of the aircraft and its equipment must be accomplished, based on the items of equipment and material contained in the applicable Log or Record.

Although the Log and Record serve the same purpose, there are some minor differences in their format and categorical listings. In general, the determination as to whether items are, or are not, subject to listing in these publications without regard as to whether they are Contractor or Government furnished and Contractor or Service installed, is governed by the following:

1. Items essential to the execution of the designated missions of the aircraft, such as armament, electronics, photographic equipment (excluding cameras other than for primary missions), and special instruments, are included.

2. Items of equipment which are rigidly fixed and considered to be a basic or integral part of the airframe, such as engines, propellers, wheels, tires, and brakes, are excluded. In the case of the Aircraft Inventory Record, standard instruments are also excluded.

3. Special equipment items essential to the safety or comfort of the crew, such as bedding, liferafts, Thermos bottles, crash axes, and portable fire extinguishers, are included. Comparable items which are personal issue or furnished on squadron allowances are excluded.

4. Loose equipment delivered with the aircraft, such as covers, mooring kits, and jack pads, for which stowage provisions have been incorporated in the aircraft, are included.

5. Items subject to pilferage or readily convertible to personal use, such as clocks, Thermos jugs or bottles, bedding, and first aid kits, are included. Comparable items which are personal issue or furnished on squadron allowances are excluded.

The Standard Inventory Log is subdivided into groups of equipment (e.g., instrument and navigation equipment, armament equipment, and electronic equipment). The components are listed in alphabetical sequence and according to their location in the aircraft, with the exception of the electronics equipment, in which case all components of an equipment are listed in one place regardless of their location in the aircraft. Stock numbers are also supplied for individual items, and are used for ready reference when replacements are required.

The Aircraft Inventory Record includes a sectional breakdown diagram of the applicable aircraft. This diagram consists of a side elevation and/or the plan view of a wing, or in the case of twin-boomed or flying wing aircraft, the perspective view.

To facilitate inventorying, the sections of the diagram are identified by letters, the letter "A" being assigned to the foremost section, "B" to the next, and so on, generally to the rear of the aircraft. The letter "R," as part of the item number, denotes items mounted on the exterior of the fuselage, and the letter "F" denotes items to which access is gained from the fuselage. Subdivisions of sections may be identified by a lowercase letter, such as "Aa," "Ac," etc.

The equipment list portion of the Record is divided into sections, each of which lists the items pertaining to a particular section of the aircraft, as indicated on the sectional breakdown diagram. Within each section, individual items are numbered as nearly as possible in the sequence of their physical location in the aircraft without regard to their relation to specific equipment. Stock numbers are not supplied as part of the equipment listing in Inventory Records.

One Standard Inventory Log in general is issued as applicable to one aircraft model and designates material and equipment peculiar among the various applicable versions and bureau numbers. The Aircraft Inventory Record is issued as applicable to one aircraft for a specific bureau number.

Blank columns are provided on the inventory pages of the Log and Record, in order that transferring and receiving activities may jointly inventory and indicate the quantity of each item ascertained to be on board the aircraft at the time of transfer. A "Receipt Endorsement Log" in the Standard Inventory Log and a "Certificate and Record of Transfer" in the Aircraft Inventory Record are provided so that transferring and receiving activities may sign, indicating by column applicability, the items on board the aircraft.

Upon the transfer of an aircraft, representatives from the transferring and receiving activities jointly inventory and record, in the appropriate column, the quantity of each item which is ascertained to be on board the aircraft at the time of transfer. When a ferry pilot or a naval vessel is involved in the transfer, two inventories are made, one prior to the ferry flight or embarkation, and one upon completion. In the former instance the ferry pilot or vessel is to be considered the receiving activity, and in the latter instance the transferring activity.

A Report of Inventory Form supplied with the Standard Inventory Log, or the Shortages Form (DD 780-2) in the Aircraft Inventory Record, is generally prepared in triplicate, listing missing items with appropriate remarks. The original signed copy of the form is retained by the transferring activity and filed as a permanent record of transfer.

The second copy of the form is left in the Standard Inventory Log or Aircraft Inventory Record, as the case may be, and delivered along with the Log or Record to the activity receiving the aircraft.

A third copy of the report or shortages form is forwarded to the cognizant major operating command of the transferring activity for information and any appropriate action deemed necessary.

In the case of missing items, the transferring activity makes every effort to locate the missing items or to withdraw from store the replacement items necessary to complete the inventory. If it is impossible to locate or supply the missing items, the notation "Missing items are not available" is placed in the Report of Inventory Form in the Standard Inventory Log or the Shortages Form in the Aircraft Inventory Record. An explanatory statement signed by the transferring representative is placed with this form, indicating the authority for these shortages. On the basis of this statement, the receiving activity may fill the shortages from stock and account for them in the normal manner.

When an aircraft is abandoned or disposed of by scrapping, the inventory log or record may be destroyed by the activity disposing of the aircraft. When the aircraft is transferred to other U. S. agencies, the log or record is transferred also. When sold to a private party, the inventory log or record is forwarded to the Naval Air Systems Command immediately after consummation of the sale and should include the signatures of the last custodian (seller) and the purchaser. In order to provide the buyer with inventory information, the log or record may be duplicated, provided that it includes no classified information.

VISUAL INFORMATION DISPLAY SYSTEM (VIDS)

The Visual Information Display System (VIDS) is a time charting management tool which provides a graphic display of vital, up-to-date information on a continuing basis. The system correlates all aircraft status information, particularly awaiting parts and flyable discrepancies, and assigns a relative importance to each item. Additionally, the system displays the amount of time required to perform any maintenance and the number of personnel available and engaged in work. The ability to review the overall situation and determine what resources are available enables the maintenance officer and maintenance control officer or supervisor to more effectively and efficiently carry out his duties. This information is displayed on specially configured cardex type display boards.

DISPLAY BOARDS

VIDS boards consist of enlarged cardex type pockets scaled horizontally to represent hourly time periods. Each pocket is overlapped by the one above so that approximately a 3/8-inch strip is visible at the bottom of the pocket. Boards are available in three sizes–100 pocket (40" x 40"), 50 pocket (40" x 26"), 25 pocket (40" x 14"), and in three standard configurations. The configurations are as follows:

1. Organizational, flight maintenance board. This board provides current status of each aircraft plus displaying scheduled/unscheduled maintenance, including outstanding flyable discrepancies, parts on order, scheduled flights, and aircraft configuration. The current and projected workload of each work center and the number of labor code 500 personnel available for work are also displayed on the board.
2. Material control status board. Outstanding material requisitions are displayed on this board by aircraft modex, work center, and document number.
3. Work center board. The work center board displays the work assignments by name in the work center plus providing space for individual technical qualifications record. Space is also provided for pending assignments, not assigned tasks, and those in AWP (aircraft awaiting parts) status. The top pocket is configured to show the status of special support equipment (SSE) required by the particular work center.

IMPLEMENTATION PROCEDURES

To make the implementation phase as smooth as possible, a thorough indoctrination of the maintenance/material control personnel and work center supervisors is necessary. All problems concerning operating procedures, information flow, and communication procedures should be resolved prior to the implementation date. Certain steps are necessary if the transition is to be made in an orderly manner with minimum disruption of the maintenance effort.

Information Display Requirements

Efficient management of the maintenance effort requires certain information concerning the resources of the activity be available. The range and depth of information requirements are determined by such factors as mission, size, and physical layout of facilities. For purposes of standardization and to insure that the minimum information requirements are displayed, the following guidelines should apply:

1. Maintenance control.
   a. Inventory of aircraft.
   b. Aircraft configuration.
   c. Aircraft airframe/engine/component/time.
   d. Aircraft/equipment discrepancy status.
   e. Work center loading.
   f. Projected flight and maintenance requirements.
2. Material control.
   a. Outstanding requisitions by aircraft and priority.
   b. Outstanding requisitions not identified to a specific aircraft.
   c. Master register listing by supply document number.
3. Work center.
   a. Personnel status.
   b. Training/qualification record.
   c. IN WORK discrepancies and personnel assigned.
   d. AWP and pending discrepancies.

OPERATING PROCEDURES

There are two approved methods of operation for the Organizational Maintenance Control VIDS. Both methods are in consonance with current OpNav directives and are adaptable to any type activity. With either method, the primary consideration is placing maintenance control in CONTROL OF MAINTENANCE.

Time Charting Method

This method is a 3-day projection–title columns with Julian date; i.e., 9060, 9061, and 9062, and continue sequence as workdays progress. At the beginning of each shift, the maintenance control supervisor will verify his status board(s) with the various work centers. Each work center supervisor will inform him of the number of labor code 500 personnel available for work. These numbers will be indicated by the use of manpower indicators on the work center sections of the board.

Each discrepancy will be transcribed on an appropriate colored maintenance control register along with other pertinent information available at that time. Red registers will be used for discrepancies that place the aircraft in a nonflyable status. Blue registers are used for flyable discrepancies that do not place the aircraft in a reduced material condition (RMC), and an orange register for discrepancies that cause the aircraft to be placed in a reduced material condition.

The maintenance control supervisor will determine whether the affected work center(s) has the capability to handle the discrepancy at the present time. In making this decision he should utilize the manpower information displayed on the work center section, the present workload, and priority of the IN WORK and PENDING discrepancies. Based on his decision, the following procedures will be used.

1. Work center has capability. Maintenance control will transmit pertinent information to the affected work center(s). At this time, the work center supervisor will provide maintenance control with the estimated time of completion (ETC), work unit code, and number of personnel that will be assigned to the task. This information is entered in the appropriate spaces of the register. An Equipment Statistical Data (ESD) card will be initiated to indicate a change in the aircraft condition. The colored tabs at the bottom of the register, in excess of the ETC, are folded under. Copy 1, along with the ESD card, is placed in the aircraft pocket or pockets under the appropriate day and time frames. Copy 2 is placed in the appropriate work center pocket in the same manner, and the "men assigned" sliding tab is adjusted to indicate number of personnel assigned. Copy 3 will be forwarded to Quality Assurance for information purposes.

2. Work center does not have capability at present time. Maintenance control will indicate on the register that the discrepancy is in an AWM (aircraft waiting maintenance) status and will schedule the work at a later date and/or time. Copy 1 will be placed in the aircraft pocket, and copies 2 and 3 in the work center pocket under the appropriate date and time frame. An ESD card will be initiated and placed in the aircraft pocket. When the discrepancy is scheduled IN WORK, procedures described above will be utilized.

The register will remain on the board in an IN WORK status until the discrepancy is completed or unless the aircraft goes AWP or AWM. AWP and AWM status are described as follows:

AWP. The existing ESD card is closed out and a new one initiated to show current status. A black tab is placed in front of the register to provide visual recognition of the AWP status. Copy 2 of the register is moved to the AWP section of the work center board. When material is received, discrepancy is rescheduled for work.

AWM. When maintenance control determines that a work center must go AWM on a discrepancy, the pertinent information will be entered. The discrepancy will be rescheduled at a later date and/or time and register copies 1 and 2 will be moved on the board to the appropriate time frame. These registers can be flagged with an appropriate color for easy identification.

When maintenance control is notified that a discrepancy has been corrected, the registers (copies 1 and 2) will be removed from the board and copy 2 destroyed. Pertinent information will be entered in the appropriate blocks of copy 1.

Copy 1 should be retained in a temporary file until the MDR document passes through maintenance control. At that time, all necessary information is verified and then the register is filed in accordance with existing instructions. Insure that the ESD card reflects the current status of the aircraft.

Current Discrepancy Status Display Method

This method utilizes three columns—PENDING, IN WORK, and AWP—each encompassing one 24-hour period. At the beginning of each shift, the maintenance control supervisor will verify his status board(s) with the various work centers. The supervisor will then determine which work centers have capability to handle incoming discrepancies. In making this decision, he should utilize the manpower information displayed on the work center section, the present workload, and priority of the IN WORK and PENDING discrepancies. Based on his decision, the following procedures will be used:

1. Work center has capability. Maintenance control will transmit pertinent information to the affected work center(s). At this time, the work center supervisor will provide maintenance control with the estimated time of completion (ETC), work unit code, and number of personnel that will be assigned to the task. This information is entered in the appropriate spaces of the register. An Equipment Statistical Data (ESD) card will be initiated to indicate a change in the aircraft condition. The colored tabs at the bottom of the register, in excess of the ETC, are folded under. Copy 1, along with the ESD card, is placed in the aircraft pocket under the heading IN WORK and time frames. Copy 2 is placed in the appropriate work center pocket in

the same manner (column and time frame), and the "men assigned" sliding tab is adjusted to indicate number of personnel assigned. Copy 3 will be forwarded to Quality Assurance.

2. Work center does not have capability at present time. Maintenance control will indicate on the register that the discrepancy is in an AWM status and will schedule the work at a later date and/or time. Copy 1 will be placed in the aircraft pocket under the heading PENDING. Copies 2 and 3 are placed in the appropriate work center pocket under the same heading. An ESD card will be initiated and placed in the aircraft pocket. When the discrepancy is scheduled IN WORK, procedures described under work center capability will be utilized.

When a discrepancy has been scheduled IN WORK, the register will remain on the board under the heading IN WORK until the discrepancy has been completed or it is necessary to go AWP or AWM.

AWP. When maintenance control determines that a work center must go AWP on a discrepancy, copy 1 is placed in the aircraft pocket under the heading AWP. Copy 2 is placed in the appropriate work center pocket under the same heading. When the material is received, the discrepancy is rescheduled for work. Insure that the ESD card reflects the current status of the aircraft.

AWM. When maintenance control determines that a work center must go AWM on a discrepancy, the pertinent information will be entered in the appropriate block of copy 1. Both copy 1 and the ESD card are then placed in the aircraft pocket under the heading PENDING. Copy 2 is placed in the appropriate work center pocket under the same heading. The discrepancy will be rescheduled at a later date and/or time and the registers (copies 1 and 2) will be moved to the appropriate pockets under the heading IN WORK. Copy 1 will be updated by entering the IN WORK time in the appropriate blocks.

When maintenance control is notified that the discrepancy has been corrected, the registers (copies 1 and 2) will be removed from the board and copy 2 destroyed. Pertinent information will be entered in the appropriate blocks of copy 1.

Copy 1 should be retained in a temporary file until the source document is received in maintenance control. At that time, all necessary information is verified and then the register is filed in accordance with existing instructions. Insure that the ESD card reflects current status of the aircraft.

Maintenance Control Information

The number of the assisting work center(s) is written in the appropriate block when a discrepancy is transcribed on a maintenance control register. A copy 2 register of the same color as the primary register is made out for each assisting work center and placed in the appropriate work center section. As each assisting work center completes their portion of the discrepancy, the source document that is submitted will be verified with the copy 1 register and that particular work center will be crossed out. The initials of the person calling in the completion will be written above the work center number.

ESD cards can be placed on the VIDS board by either placing the card behind copy 1 of the register or inserting the card in the pocket on the extreme left side of the board. In this manner, the status block of the card is visible.

Work Center Information

When a discrepancy is received by the work center supervisor, pertinent data is recorded on the work center register. The supervisor informs maintenance control of the ETC, WUC, and the number of men that will be assigned to the task. The register is then placed in the pocket under the heading IN WORK and parallel to the name of the person given responsibility for the task. A distinguishing tab (or number) can be placed in any corresponding pocket(s) of other personnel assigned to the repair action. The register remains on the board until the discrepancy has been completed or it is necessary to go AWP or PENDING. If either of these two conditions occur, the register is removed from the IN WORK section, annotated with the proper information, and maintenance control is notified of the work status change. The register is then placed either in the AWP or in the PENDING section of the work center board. When the material has been received or the task rescheduled by maintenance control, the register is updated and placed in the IN WORK section of the board. When the task has been completed, the work center register is completed and the pertinent information is passed to maintenance control.

The completed register is verified against the completed source document prior to the document being passed on to maintenance control. The register will be retained in a temporary file until verification of the daily MDR readout is accomplished, then filed in accordance with existing instructions.

Calendar Maintenance Procedures

When an aircraft is inducted into a calendar inspection, maintenance control will initiate an appropriate maintenance control register with a controlling JCN. Copy 1, along with an ESD card, is placed in the appropriate aircraft pocket. Copy 2 is placed in the pocket of work center 140 to indicate one aircraft inducted for inspection. All registers are removed from the VIDS board (copies 1 and 2) and are consolidated, by JCN order, on an outstanding discrepancy control form. The control JCN and maintenance control registers, with the outstanding discrepancy control forms, are issued to the calendar maintenance supervisor.

Upon induction of an aircraft into calendar inspection, the calendar maintenance supervisor will perform all maintenance control functions until completion of the inspection. All pending registers will be displayed in the same manner as maintenance control's board; i.e., copy 1 in the aircraft pocket, and copy 2 in the applicable work center pocket. When a look phase or a fix phase register is initiated, they also will be displayed in the same manner. Upon notification of a task, each applicable work center supervisor will initiate a work center register and will display them in accordance with work center supervisor's procedures. The calendar maintenance supervisor must notify maintenance control of any change that affects ESD reporting. When the inspection is completed, the control document will be signed off. All flyable discrepancies that are still outstanding should be listed on an outstanding discrepancy control form by JCN order. All registers (copies 1 and 2), the outstanding discrepancy control form, and the control document will be turned in to maintenance control.

When maintenance control is notified the calendar inspection has been completed, registers (copies 1 and 2) are then removed from the VIDS board. Annotate copy 1 and file in accordance with existing instructions, and destroy copy 2. Update the ESD card to reflect the current status of the aircraft. Place a flight card in the aircraft pocket with a red tab to indicate a test flight is required. Display all flyable discrepancies (copies 1 and 2) in the aircraft pocket and appropriate work center sections of the maintenance control board.

CHAPTER 3

SUPERVISION RESPONSIBILITIES

The job of supervising the operation of a division or shop is a many sided task. Some of the techniques will have been learned through past experience. Others may be learned from self-study courses and technical publications. Still other techniques will have to be learned during the actual supervision of the division or shop. The purpose of this chapter is to acquaint the new supervisor with some of the more important aspects of shop supervision.

OBJECTIVES OF SUPERVISION

Briefly, the objectives of supervision are as follows:

1. To operate with maximum efficiency and safety.
2. To operate with minimum expense and waste.
3. To operate free from interruption and difficulty.

While these are the primary objectives of shop supervision, it is well for the man who may be assigned these duties to keep in mind the fact that his new assignment is important to him personnally, since it affords him in an excellent opportunity to gain practical experience toward future promotions.

OPERATION WITH MAXIMUM EFFICIENCY AND SAFETY

The operational efficiency of a shop is dependent to a large extent upon how conveniently the work spaces and equipment are arranged in the shop and upon the extent to which the shop, files, and equipment are maintained. Equipment in good working order, tools in good shape and of the proper type and quantity, and an up-to-date file of applicable publications are all important factors toward a smoothly running aircraft maintenance shop.

As some equipment becomes obsolete and new equipments and new models of equipment are phased into the shop inventory, the efficiency will increase to a certain extent, but may still be short of the full potential. Making a drastic rearrangement to improve the utilization of a single piece of equipment may not be economically feasible; however, a drastic change which results in improved utilization of several equipments may be worthwhile. The new shop supervisor will want to make an evaluation of the existing shop layout to assure himself that he has the most efficient arrangement possible.

The shop functions may be further smoothed by the judicious delegation of authority to individuals next in seniority to the supervisor. The delegation of authority does not relieve the supervisor of the final responsibility for work accomplishment. It is primarily a means of relieving the supervisor of details. A supervisor who allows himself to become too involved with details loses his effectiveness as a supervisor.

A supervisor should know his men's limitations and capabilities in order to get the most work out of them. He should exploit the capabilities of his best men in a twofold manner. If at all possible he should assign a well-qualified man to do a certain job and add to the team other individuals who are less qualified but who are professionally ready for advanced on-the-job training.

The supervisor must anticipate the eventual loss of his most experienced workers through transfers, discharges, etc., and offset this by the establishment of an effective and continuing training program. In addition to raising the skill level of his division, the training program will insure that personnel, otherwise qualified, will be ready for the advancement in rating examinations.

A shop safety program must be organized and administered if the shop is to function efficiently. Current Navy directives and local policies are quite specific as to the establishment of safety training programs. A worker is not much good to anyone if he is laid up in the sickbay.

The keeping of accurate and complete records is another factor in the efficient operation of a shop. This includes records of usage data, work accomplished, and personnel progress. The most efficient recordkeeper is one who has enough records without having his files bulging with useless and outdated material.

A knowledge of the principles of man-hour accounting is necessary in the efficient utilization of the manpower available. The supervisor should schedule his workload in such a way that planned absences of key workers will not unduly interrupt the daily routine. When scheduling the workload, he should keep in mind the skill level required for the various tasks and assign individuals to jobs in such a way that the work may still progress if any worker is unexpectedly absent.

OPERATION WITH MINIMUM EXPENSE AND WASTE

The efficiency of any operation is directly related to the expense involved. The shop supervisor has responsibility for ordering and accounting for parts and materials. He must impress upon his men the need for being thrifty in the use of these materials. There are many ways to economize, and the supervisor and his senior petty officers should always be on the alert for opportunities to point out these ways to the less experienced individuals.

Methods of avoiding waste and unnecessary expense should be included in the shop training program.

PROVIDING FOR INTERRUPTIONS

During an average workday, occasions will arise when personnel have to leave their working spaces for one reason or another, thereby delaying the scheduled work. Some delays can be anticipated; some cannot. Among the delays that can be anticipated are training lectures, immunization schedules, flight schedules, rating examinations, meals, and watches and other military duties.

Before making personnel work assignments the supervisor should determine what delays can be anticipated. It may be possible to arrange assignments so that work interruption is held to a minimum. When estimating the completion time of an aircraft maintenance task, the supervisor should allow for these predictable delays.

UNFORESEEN DIFFICULTIES

Some difficulties are impossible to predict. The weather, for instance, cannot be relied upon for full cooperation in the maintenance effort. The supervisor must have a flexible schedule planned to provide for such events if he expects to contribute maximum support to his unit. The flight schedule itself is seldom ever completed without a few changes. Usually these changes will involve a rearrangement of previously planned maintenance tasks. Again the supervisor must be as well prepared for such interruptions as possible and be able to reassign his men, if necessary, with the least amount of confusion and loss of time.

SHOP ORGANIZATION

A well-organized shop will provide a safe and comfortable working area, allow for maximum use of space available, and produce the most toward the maintenance effort.

SHOP LAYOUT

The average Chief or First Class Fire Control Technician may never have the opportunity of planning the layout of an Avionics shop in a new facility. In almost every case, the new supervisor will take charge of an already functioning division or else, when his squadron or unit moves to a new base, he and his crew will usually be assigned to spaces already basically equipped. In either case, a re-evaluation of the shop's layout is indicated. This re-evaluation should include checking the most recent applicable allowance lists to see if the shop equipment allowances have been changed in any way. There is no use relocating equipment which involves rewiring work if improved replacement models are authorized and available.

A change in assigned aircraft model designation may call for a re-evaluation of the shop layout. Avionics shops contributing to the aircraft maintenance program of an F-8 squadron may have to be rearranged somewhat if the Crusaders are replaced with F-4 aircraft.

When planning for new installations, the supervisor should utilize the Design Guide for Avionics Shop Power Distribution, NavWeps 01-1A-512.

The ideal setup contains enough space to have all the avionics shops in separate spaces in a centrally located area. Since this is not always possible, the supervisor must decide what shops are to be combined, if any, and in what areas of each space the appropriate equipment is to be installed This decision should be based on factors of safety, economy, functional compatibility, and convenience.

The shop layout plan should make provisions for an information or bulletin board upon which may be posted safety posters, maintenance posters, instructions and notices, plans-of-the-day, watch bills and such other information as is appropriate from time to time. The bulletin board should be located in a prominent place in the shop, preferably near the entrance where everyone assigned will have to pass at some time or another during the day. Material on the bulletin board should be changed frequently, expired notices promptly removed, the current plan-of-the-day posted early, and other posters and materials rotated periodically. If the same material is presented in the same format every day, it will not be long before the men begin to ignore the bulletin board and purposes for having it are defeated. New arrangements are noticed and interest is stimulated with variety.

BENCH ARRANGEMENT

Following the determination of what shops are to occupy what spaces or areas within a space comes the arrangement of furniture and equipment for the various shops.

The arrangement of the shop furnishings should be made on the basis of utility rather than appearance. Moving an item of equipment into an out-of-the-way corner may greatly improve the appearance of the shop but at the same time reduce the efficiency of personnel using the equipment and may possibly create a safety hazard. A good rule to follow is to locate equipment where it can be safely used by the greatest number of people with a minimum of effort in the least amount of time.

In view of the fact that standard avionics workbenches are normally used in shops where actual maintenance and testing of equipments are accomplished and that these benches usually become fixed in their position (due to test harness and cabling arrangements) there will be few benches or worktables to consider. Worktables or workbenches that are not permanently installed should be positioned with respect to fixed equipment so that they can be safely, quickly, and easily reached when work is being performed that requires their use. In an area where intricate maintenance functions are to be performed, such as disassembly and repair of miniature components, consideration should be given to cleanliness and to special interference-free type lighting.

If a separate shop space is not provided for classified equipments, then placement of these equipments in a section of the shop where the physical arrangement provides limited or controlled access is desired.

SAFETY

Operational readiness of a maximum number of aircraft is necessary if naval aviation is to successfully perform its mission. Keeping its aircraft in top operating oondition is the principal function of naval aviation maintenance personnel. It is essential that maintenance work be performed with a minimum of injury to personnel and damage to equipment and aircraft.

Aircraft maintenance is, to some extent, naturally hazardous due to the nature of the work, the equipment and tools involved, and the variety of materials required to perform many repairs and maintenance functions. Factors which can function to increase or decrease these hazards are (1) the experience levels and mental attitudes of assigned personnel, and (2) the quality of supervision of the maintenance tasks. Thorough indoctrination of all personnel is the most important single step in maintaining safe working conditions.

The concept of aircraft maintenance safety should extend beyond concern for injury to personnel and damage to equipment and aircraft. Safe work habits go hand-in-hand with flying safety. Tools left in aircraft, improper torquing of fasteners, and poor housekeeping around aircraft can cause conditions which may claim the lives of flying personnel as well as cause strike damage to aircraft. Safety on the ground is equally as important as safety in the air.

A recent type commander letter states in part, "While the increased complexity of our modern aircraft is a factor, it is noted that a large number of maintenance-error-caused accidents and incidents are due, not to complexity of equipment, but to lack of supervision and technical knowledge. Many mistakes are simple ones in routine maintenance."

Safety in aircraft maintenance depends largely upon the supervisory personnel. The standards of quality which they establish are directly reflected in the quality of the aircraft maintenance. The primary duty of the senior petty officers is to supervise and instruct others rather than to become totally engrossed in actual production. Attempts to perform both functions invariably result in inadequate supervision and greater chance of error. Supervisors must exercise mature judgement when assigning personnel to maintenance jobs. Consideration must be given to each man's experience, training, and ability.

Sometimes overlooked in a maintenance program are the considerations generally grouped under the term "human factors." These factors are important in that they determine if an individual is ready and physically able to do work safely and with quality. Supervisory personnel should be constantly aware of conditions such as general health, physical and mental fatigue, unit and individual morale, training and experience levels of personnel, and other conditions which can contribute in varying degrees to unsafe work. Not only is it important that proper tools and protective clothing and equipment are available for use, but also the insistence by maintenance supervisors that they are used is of increasing importance with modern high performance aircraft. For example, maintenance personnel are sometimes negligent in the wearing of protective hearing devices in high noise areas.

Technical knowledge also plays a large part in a good maintenance safety program. The complexity of our modern equipment demands the attention of well-informed and expert maintenance personnel; otherwise, our weapons systems cannot be operated and maintained. Technical knowledge is a function of education and training which, incidentally, does not end with graduation from Class A school. Graduation is only the beginning. Any AQ worthy of his rating is continually training and learning through self-study and application, and through a personal desire for proficiency and self-betterment. But technical knowledge by itself is not sufficient unless it is coupled with an old-fashioned craftsmanship that receives gratification and keen satisfaction in doing any job well. The man who wishes to contribute to safety and reliability improvement must know his job and must develop professional pride in the quality of his work.

It is a continuing duty of every person connected with aircraft maintenance to try to discover and eliminate unsafe work practices. Accidents which are caused by such practices may not take place until a much later date and their severity cannot be predicted. The consequences may range from simple material failure to a major accident resulting in serious injuries or fatalities.

There are several areas in which the shop supervisor can effectively work to minimize accidents incident to aircraft maintenance. Among these are continuing inspections of work areas, tools, and equipment; organization and administration of safety programs; correct interpretation of safety directives and precautions; and energetic and imaginative enforcement of them.

ELIMINATION OF HAZARDS

Most accidents which occur in noncombat operations can be prevented if the full cooperation of personnel is gained and vigilance is exercised to eliminate unsafe acts. The supervisor should diligently inspect work areas, tools, and equipment to detect potentially hazardous and unsafe conditions and take appropriate corrective action. Since maintenance personnel will be working in the shop, in the hangar, and on the line all of these areas should be included in the supervisor's inspection. He should check for explosion or inhalation hazards due to improper ventilation of working spaces, or careless handling of materials.

Spilled oil, grease, and chemicals should be wiped up promptly, and all rags used should be disposed of in covered metal containers.

Handtools should be in good shape, of the proper type, and used only for the purpose for which they were designed.

Fire hazards present another serious problem. "No smoking" rules should be strictly enforced. Ground wires should be properly installed on every aircraft during maintenance to eliminate dangerous static electrical buildups.

GROUNDING

Grounding power tools and other equipment is a must and the supervisor is the man to see that this is done. It should not be necessary for a technician to be killed to once again emphasize the absolute necessity that portable power tools and other equipment be properly grounded. The importance of installing safety grounds to the cases of power tools or equipment must be stressed as a case of life or death—that is exactly what it is.

Another aspect of this problem, which deserves attention is a poor safety ground or one that is wired incorrectly. This may be more dangerous than no ground at all. A poor ground is dangerous because it does not offer full protection, yet it lulls the user into a false sense of security. The incorrectly wired ground is a hazard because transposing one of the line wires and the safety ground makes the shell of the tool "hot" the instant the plug is connected. Thus the unwary user is trapped unless, by pure chance, the safety ground is connected to the grounded side of the line on a single-phase grounded system. In this case, the user again goes blithely along using the tool until he encounters a receptacle which has its wires transposed.

The need for a safety ground is not hard to realize when you know that a few years ago statistics showed that, over a given period, 50 percent of the deaths in the Navy due to electric shock were caused by 115-volt electric potentials.

The reason for this high percentage is as follows: When the current through the body nears 100 milliamperes, death is almost certain. The body resistance, assuming dry skin, varies from about 1,000 to 500,000 ohms. With a 115-volt potential, a body resistance as low as 1,150 ohms can produce the necessary 100 milliamperes. With perspiration or water on the victim's hands, the body's resistance can go as low as about 300 ohms, resulting in a current of 384 milliamperes, which is normally lethal.

Portable power tools afford you an excellent opportunity to become part of a circuit. For example, if the motor winding is shorted to the case, the case will be at the same potential as the power applied. Then the path of least resistance may be you.

These facts caused SecNav to formulate the policy of grounding any exposed, noncurrent-carrying parts of electrically operated equipment powered from supply circuits of more than 50 volts. Several safety measures have been adopted to implement this policy.

In an effort to make certain that a safety ground is used, a requirement has been established for a 3-wire, color-coded cord with a polarized plug having a ground pin.

Since the polarized plug can be connected only to a mating receptacle, the user has no choice but to use the safety ground. (Adapters to change three-prong plugs to two-prong plugs are sometimes furnished, but they should never be used with power tools.) Supervisors should insure that the ground pin is not removed from the polarized plug. The color coding has been standardized to conform with the National Electric Code. All new tools which are properly connected use a green wire as the safety ground. The wire is attached to the metal case of the tool at one end and to the grounding pin in the connector at the other end. It normally carries no current, being used only when the tool insulation fails to bypass the current around the user to ground. Black and white leads are used as the current-carrying conductors: the white lead is the power ground of a single-phase system, and the black lead is hot.

The three-pin plugs and their receptacles have been designed to minimize the possibility of incorrect wiring. Looking at the end of a plug, you will notice that the pins are constructed so that they can be put into the receptacle in only one position. The ground pin is the longest and therefore will mate first and break last, insuring that the safety ground is connected at all times when power is applied to the circuit. In addition, the plugs are usually color coded. The three-prong plugs ordered under FSN N5935-280-2380 (Connector Plug, Electrical) have color-coded screws: The terminal screw on the safety ground prong is painted green; the neutral prong and screw are silver; and the terminal screw on the hot pin is brass. Thus, there should be no confusion when installing this type of plug.

One fact must be kept in mind when installing safety ground hardware. Although all portable power tools need this feature, some items of sensitive test equipment should not have their cases grounded. Grounding the case of some VTVM's, for instance, creates a possible ground loop which will support spurious signals, thereby hindering measurement accuracy.

If a cable requires replacing, be certain to replace it with the proper color-coded cord; and make sure that the green conductor is connected to the shell of the equipment. If the shell consists of more than one piece, make sure that all pieces are connected. Clean off any paint, and scrape the metal beneath it to make a clear, clean surface at the point of connection.

When it is necessary to use an extension cord, use only the type that has a grounded plug attached to one end and a grounded receptacle (suitable for connecting to the grounded tool plug) on the other.

If the tool or equipment is adequately grounded through a supporting bracket or bulkhead fastener, you need not use the ground cable. For your own protection, however, you should check the resistance to ground with a low-reading ohmmeter to be certain that the grounding is adequate (less than 0.1 ohm is acceptable). If the resistance indicates greater than 0.1 ohm, use either a separate ground strap or a three-wire cord; and check the ground connection to be certain of a good contact.

When installing a new cord or checking the tool for safety, examine the cord connections carefully. The cable wires should terminate in a standard crimped or solder type lug or connector; or, if stranded wire is used without a lug, the ends should be solder dipped. Form the wire into a loop (in the direction of the screw rotation) around the connecting screw; and make absolutely certain that no loose, fine strands of the flexible wire cord protrude to cause an accidental contact with the shell of the tool, receptable, or plug.

High Voltage

All radars employ voltages which are dangerous and may be fatal if contacted. Practical safety precautions have been incorporated into every radar system; however, when the most basic rules of safety are ignored, the built-in protection becomes useless.

The following rules are basic and should be followed at all times by all personnel when working with or near high voltage circuits:

1. CONSIDER THE RESULT OF EACH ACT–There is absolutely no reason for an individual to take chances that will endanger his life or the lives of others.
2. KEEP AWAY FROM LIVE CIRCUITS–Do not change tubes or make adjustments inside the equipment with high voltages on.
3. DISCHARGE HIGH VOLTAGE CIRCUITS–Insure that all high voltage circuits are completely discharged before working on/around the components. Even though the equipment has not been turned on recently the danger still exists.
4. DO NOT SERVICE ALONE–Always service equipment in the presence of another person capable of rendering assistance or first aid in an emergency.
5. DO NOT TAMPER WITH INTERLOCKS–Do not depend on interlocks for protection; always shut down equipment. Never remove, short-circuit, or tamper with interlocks except to repair the switch.
6. DO NOT GROUND YOURSELF–Make sure you are not grounded when adjusting equipment or using measuring equipment. Use only one hand when servicing live equipment.
7. DO NOT ENERGIZE EQUIPMENT–If there is any evidence of water leakage; repair the leak and wipe up the water before energizing.

These rules, teamed with the idea that "voltage is not a respecter of persons" and that personal caution is your greatest safeguard, may prevent serious injury or even death.

ORGANIZATION AND ADMINISTRATION OF SAFETY PROGRAMS

In accordance with the Navy policy of conserving manpower and material, all naval activities are required to conduct effective and continuous accident prevention programs. The organization and the administration of a safety program are part of the requirements of the supervisor. The safety program must be in accordance with local instructions and based on information contained in the Navy safety precautions manuals which are presently undergoing a revision. Work methods must be adopted which do not expose personnel unnecessarily to injury or occupational health hazards. Instructions in appropriate safety precautions are required to be given and disciplinary action taken in case of willful violations.

The shop safety program will generally involve three areas of attention–the posting of the most important safety precautions in appropriate places, the incorporation of safety lessons in the formal training program, and frequent checks for understanding during the day-to-day supervision of work.

Posted safety precautions are more effective if they may be easily complied with; for example, a sign on the RADAR test bench reads "ground high voltage of PFN before working on or near modulator." Thus, a high voltage discharge probe should be properly installed in a convenient location.

Fixed posters and signs should be renewed frequently and not allowed to become rusty, faded, or covered with dust and dirt. General safety posters on bulletin boards and other places should be rotated often to stimulate interest. Appropriate safety posters may be obtained from the squadron or unit safety officer.

The formal safety training sessions should utilize films, books, visual aids, or any other suitable technical material. The men should be told more than just what or what not to do. Each safety subject should be explained in detail. The results of unsafe acts are usually the most dramatic and easiest remembered. Causes of accidents and contributing factors should be reviewed and analyzed. Many good ideas for accident prevention have been developed in training sessions.

An extensive series of lessons may be

developed over a period of time as latent hazards are recognized, and this will aid in keeping the sessions interesting while avoiding too frequent repetition.

It may be well to mention the new man in the shop at this point. A separate safety indoctrination lesson which covers all the major hazards of the shop should be given the new man as soon as he reports for work. The supervisor with an effective safety program and an excellent shop safety record will take steps necessary to make sure that the new man is properly instructed, so as to prevent his being hurt.

In the third area of safety program administration–followup, the supervisor will do well to delegate authority to his subordinate petty officers to assist him in monitoring the program. Also included in the followup area is a responsibility of the shop supervisor to inquire as quickly and thoroughly as possible into the circumstances of accidents and reports of unsafe practices and take action or make recommendations.

Safety precautions are designed to cover usual conditions in naval activities. Commanding officers and others in authority are authorized to issue special precautions to their commands to cover local conditions and unusual circumstances. The shop supervisor will have to apply both sets of rules in the administration of his shop safety program.

Safety directives and precautions should be followed to the letter in their specific application. Should any occasion arise in which any doubt exists as to the application of a particular directive or precaution, the measures to be are those which will achieve maximum safety.

When new safety posters or precautions are posted, it is the responsibility of the shop supervisor to correctly interpret their application to his men. In this way he will be able to achieve a unity of thought and action in the observance of the required safety rule.

The organization's safety officer is available to assist in interpreting and suggesting ways of implementing various safety directives and precautions. Current directives require that a safety officer or safety engineer be assigned as head of the safety department, division, branch, or section, whichever is applicable, at all shore stations.

In most instances the hazards involved and the applicable precautions for a given type of work are the same whether the work is done afloat or ashore.

RADIOACTIVE TUBES

Radioactive material is used in quite a number of spark gap, TR, glow lamp, and cold cathode tubes.

In many cases the personnel charged with maintenance of equipment that contains radioactive material are not aware that they are handling radioactive matter. Even if they do know, they are quite likely to take the matter too lightly.

Radioactive materials are intentionally added to the tubes to produce a continuous supply of ionized particles in the tubes. This assures that the tubes will always operate at the same voltage.

The radioactive material causes the tube to produce a continuous supply of ionized particles whether the tube is in storage, in transit, in the equipment, or in disposal containers. The general concept is that ionization occurs only when the keep-alive voltage is applied to the tube. This is fallacious, since the voltage only increases the rate of ionization; it does not affect the rate of decay of the radioactive material.

Radiological Hazards

Radioactive tubes, as normally used and stored aboard stations and ships, do not subject personnel to a dangerous amount of external radiation. As long as the radioactive tubes are not broken, the hazard is slight; but as soon as the tubes are broken, the hazard is increased because internal radiation is then possible by inhalation of radioactive materials. However, they should be handled very carefully to prevent breakage; also, it is recommended that technicians do not remove radioactive tubes from cartons until they are ready to be used. This will preclude the possibility of the accumulation of unpacked tubes and help prevent accidental breakage.

Handling Broken Tubes

When a radioactive tube has been broken, it is advisable to observe the following rules, which apply when any material is contaminated by radioactivity:

1. Contact a medical officer.
2. Never permit any material contaminated by radioactivity to come in contact with any part of the body at any time. Wear rubber or plastic gloves at all times when it is necessary to handle radioactive wastes or broken radioactive parts.

3. Do not bring food or drink into the contaminated area or near any material that is radioactive.

4. Immediately after leaving the contaminated area, if you have handled radioactive material in any way, remove any clothing which might have become contaminated, and wash your hands and arms thoroughly with soap and water, especially before eating, drinking, or smoking.

Disposal

In order that the Atomic Energy Commission (AEC) shall have cognizance of all disposal areas, amounts deposited in each area, and disposal procedures, SecNav Instruction 4555.1 directs that all naval activities shall dispose of radioactive waste by transferring them to an activity licensed by the AEC or to an AEC land disposal site, except in certain cases which are described in the instruction.

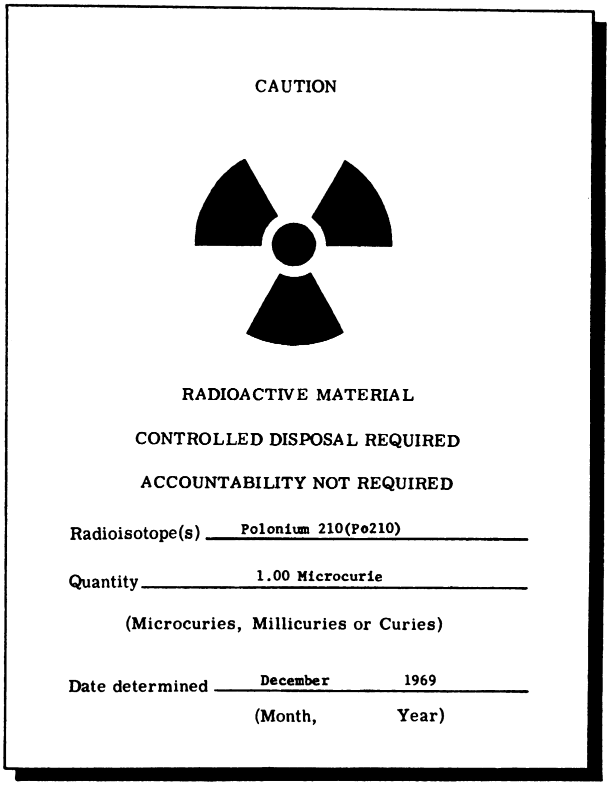
In general, radioactive electron tubes should not be disposed of individually, but should be collected in a designated container with a tight-fitting lid and suitable markings until a reasonable quantity for disposal has been gathered.

Tube and Container Markings

There are two types of marking or labeling of commodities and their containers, based on the level of activity of the radioisotope contained. Detailed information concerning the requirements of these markings and a list of the radioactive isotopes can be found in MIL-M-19590C.

Type I or type II markings must be placed on the radioactive source enclosure and on each surrounding container so that the presence of the radioactive material can be readily recognized and its location determined.

The color of both type I and type II symbols and the words "DANGER" and "CAUTION" will be magenta on a yellow background. Type I marking is as shown in figure 3-1. The words "controlled disposal required" mean that, as directed by SecNav Instruction 4555.1, naval activities must dispose of radioactive wastes through organizations licensed by AEC or through AEC land disposal sites whenever practicable. AEC controls the disposal locations and the amount of radioactive material deposited at each location in order to reduce potential hazards to the public.



CAUTION

RADIOACTIVE MATERIAL

CONTROLLED DISPOSAL REQUIRED

ACCOUNTABILITY NOT REQUIRED

Radioisotope(s) Polonium 210(Po210)

Quantity 1.00 Microcurie

(Microcuries, Millicuries or Curies)

Date determined December 1969

(Month, Year)

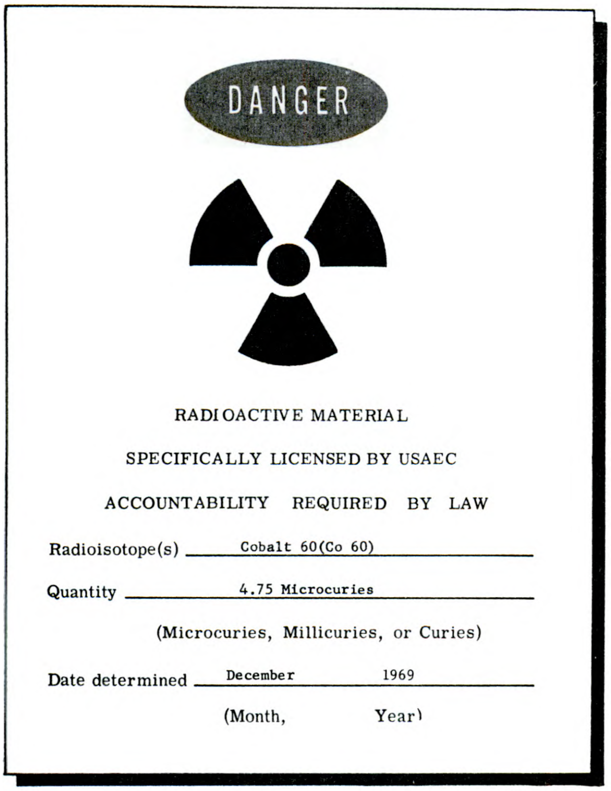
AQ.3

Figure 3-1.—Type I marking.

Type II marking is shown in figure 3-2. The words "accountability required" means that each organization that uses and/or stocks radioactive tubes must keep records showing the receipt, transfer, export, and disposal of such items in accordance with existing instructions. For special instructions concerning type II marking, refer to MIL-M19590C.

CARE OF TOOLS AND TEST EQUIPMENT

One of the problems of the supervisor will be the care and proper use of tools and test equipment. It is sometimes difficult for some men to realize the need of a special effort in the care of the tools and other equipment necessary in the performance of their work. There are two main reasons for taking special care of these items: First, maintenance would be impossible without them; and second, they are costly and therefore are sometimes in limited supply.



DANGER

RADIOACTIVE MATERIAL

SPECIFICALLY LICENSED BY USAEC

ACCOUNTABILITY REQUIRED BY LAW

Radioisotope(s) Cobalt 60(Co 60)

Quantity 4.75 Microcuries

(Microcuries, Millicuries, or Curies)

Date determined December 1969

(Month, Year)

AQ.4

Figure 3-2.–Type II marking.

The care of these items includes using them only for the purpose for which they were designed. A case in point is the use of the "Phillips" and "Reed and Prince" screwdrivers interchangeably. Most technicians have seen the tool and equipment damage caused by this malpractice. Other items such as soldering irons and guns, files, test leads, and small meters are among those which receive the most abuse.

Test equipment is expensive and delicate; therefore, the care and proper use of this equipment will be of great concern to the supervisor. If the care of such equipment is not emphasized, it will soon deteriorate to a point where it is useless and, in fact, may even become dangerous. Insure that all test equipment is calibrated in accordance with the Naval Air Systems Command calibration program, NavAir Instruction 4355.4. Meter leads must be properly stowed to prevent loss or damage; and if a cover is provided, it should be installed when the meter is not in use.

A system of stowing tools and other equipment must also be devised. The place for all tools should be marked, and everything not being used should be returned to its proper place. Toolboxes issued to shop personnel should contain a duplicate inventory list of tools issued with the box. The original should be kept in the shop files. Periodic inventory of these toolboxes is necessary since it is impossible to operate without an occasional loss or damage of tools.

TRAINING OF PERSONNEL

Training of personnel is a necessary function and one of the most important responsibilities of the supervisor. Even if a supervisor is fortunate enough to have a group of men who are highly skilled and well trained, he will find that training is still necessary. For example, the training of strikers and lower rated men for advancement in rating examinations is a continuing, neverending process. The Navy rotation policy being what it is, all men will eventually be transferred and replacements will be received aboard. The replacements will, in most instances, require training before they can be relied on to take their places as effective members of the shop organization. These and similar problems require the supervisor to be well versed in the several aspects of training—able to set up as well as conduct an effective training program for assigned personnel.

ORGANIZING A TRAINING PROGRAM

Organizing a shop training program involves such considerations as determining objectives of the training program, selecting and qualifying instructors, making arrangements for classroom space, phasing the training program with the scheduled workload, procuring training aids, and determining teaching methods for each lesson or lesson series.

The subject matter areas to be included in the shop training program are (1) material relating to maintenance of aircraft supported, (2) general material required by the men for advancement in rating examinations, and (3) material relating to safety. In most cases lessons will fall under more than one of the subject areas.

Once it has been determined what publications will adequately cover the subject areas, the material must be divided into lessons, and lesson guides prepared. It will be very helpful to assign numbers to the lessons and provide a personnel training progress record for each individual. These will provide a handy index to the state of training of the shop personnel as a whole.

Whether the shop supervisor teaches the lessons himself or assigns other petty officers to conduct them depends on the state of training of his first and second class petty officers. A requirement for advancement for third class petty officers and nonrated personnel is satisfactory completion of the correspondence course based on Military Requirements for Petty Officer 3 & 2 NavPers 10056-B. Chapter 9 in that text book sets forth some of the basic principles of training in general and teaching in particular.

An advancement requirement for second and first class petty officers is satisfactory completion of the correspondence course based on Military Requirements for Petty Officer 1 & C, NavPers 10057-B. The latter text expands and amplifies training theory and introduces job analyses, training aids, and testing. For the first time in his career the prospective First Class AQ is required to demonstrate his ability to formally teach, use various training aids, and prepare and administer written tests. In order to demonstrate correct instructional techniques the shop supervisor may elect to teach certain lessons himself or assign them to a competent instructor for the same purpose. Later he may assign less proficient petty officers as instructors so that they may acquire the experience necessary for completing their practical factors for advancement.

If at all possible, training sessions should be conducted at the same time of day and on a regular schedule. Factors to consider when scheduling lessons are usual flight schedules, meal hours, watches, availability of classrooms, and aircraft inspection schedules.

Some lessons are better suited for one type of instructional technique than others. The type of presentation for each lesson should be planned in advance. This will also facilitate the rotation of the lessons among the petty officers who require experience in teaching.

The effectiveness of aviation technical training is greatly enhanced by the use of training aids. The shop supervisors should always be on the alert for material that can be utilized as training aids. He must be aware of the existence of applicable training films and, if they are available, schedule them for showing in conjunction with specific lessons. The squadron or unit training officer may usually be depended on to supply training aids in support of shop safety presentations.

When planning a training program, the supervisor should decide where the classroom sessions should be conducted. The space selected should preferably be in a quiet area or at least one with a minimum of noisy distractions. The area should be large enough to accommodate the expected student load and be well lighted. Adequate ventilation will help keep the men awake and interested in the presentation. Convenience is another factor in the selection of classroom space. Some of the desirable space characteristics may, on occasion, have to be sacrificed in order to find a classroom nearer to the working area.

Training procedures are of two general types–formal training which can be scheduled, and informal training which cannot be scheduled.

Formal Training

Formal training is normally conducted in the classroom through lectures, supplemented by required reading and implemented by the use of all available visual aids. The schedule is prepared and published periodically by the maintenance officer. It lists the time of the training, the location of the classroom, names of the men who are to attend, subject of the lesson, and the name of the instructor.

Lesson guides are prepared by the division officer and chief or first class petty officers who are qualified to do so. The lesson guides should contain the title, objective(s), time to be consumed in presenting the lesson, list of instructional aids, list of references, outline for presentation, and a summary of the lesson.

When a petty officer has been assigned to instruct a given lesson, it is his responsibility to procure a copy of the lesson guide and from it prepare his lesson plan. Lesson plans are prepared by each individual instructor, based on the lesson guide; and though they may differ from instructor to instructor, they must adequately cover the subject.

SPECIALIZED TRAINING.–At most major naval air stations there will be a Naval Air Maintenance Training Group which offers courses of varying lengths on specific aircraft and systems. These courses are normally made available through the replacement air wing training division.

Some Naval Air Rework Facilities offer special courses on repair of certain electronic equipments. These, as well as other C-type courses, provide the supervisor with a source of specialized formal training that the man may attend on a returnable basis.

In addition to the courses mentioned previously, engineers (NAESU) of the Naval Aviation Engineering Service Unit are ready, willing, and able to assist in training of maintenance personnel. These people usually have the latest "Hot Dope" and should be consulted at frequent intervals.

Informal Training

Informal training is the practical instruction of men in the performance of maintenance tasks by means of demonstration and imitation under personal supervision in the shop or on the operating line. Nearly every maintenance task that is undertaken presents an opportunity for on-the-job training. The experienced men of the division are utilized as fully as possible in demonstrating and imparting their skills to the less experienced.

Under this system, the trainee has the opportunity to actually do the job under the supervision of an experienced petty officer. The only equipment necessary is the job itself. It is necessary, of course, that the instructor have an interest in the job and the skill to do it well. The striker or trainee will learn by seeing the job performed, and he will gain experience by having a chance to participate in the accomplishment of the job.

The nature of informal training makes regular scheduling impracticable. Actually, it is done at every opportunity. A training syllabus is prepared under the guidance of the maintenance officer, with content and scope corresponding with practical factor requirements of the personnel. On-the-job training is reported by the leading petty officer instructors and shop supervisors to the division officers on the training syllabus at regular intervals so that a close watch may be made on individual progress. The records are for review by higher authority and will point out the need for training in special areas as well as certain practical factors. The degree of success in on-the-job training depends on the degree of recognition by each individual of his responsibility to his outfit to impart his skill and knowledge to the man who is trying to learn.

TRAINING RECORDS

Since all men are not present at each unscheduled training period nor do they attend the same scheduled classes, it is apparent that they will become trained to different levels on different equipment. Obviously the supervisor must see that a record is carefully kept on each man, with an entry made each time he undergoes instruction.

Methods of recordkeeping are many and varied, but it is best to keep them in the most simple and easy-to-read form. The more elaborate the system, the more difficult it is to maintain. There are standard forms available which can be used for planning as well as for record purposes. These forms are designed to reduce recordkeeping to a minimum. Detailed information concerning recordkeeping methods can be found in Military Requirements for Petty Officer 1 & C, NavPers 10057-B.

JOB PRIORITY

Determining which jobs are to be performed first is one of the major responsibilities of the supervisor. This is an important phase of the maintenance operation because it will determine the use of facilities, men, material, and other equipment. The two major factors to consider when determining which job should come first are time and personnel required to complete the job.

Probably the most important single aid in estimating time and personnel requirements for aircraft maintenance tasks is the Periodic Maintenance Requirements Manual with its related cards, charts, and forms. Extensive time and motion studies of the various inspection requirements have been made and completion times are furnished in man-hours or man-minutes. These times also reflect routine maintenance, adjustment, and replacement if required in connection with the aircraft inspection. They are calculated on the basis that the most efficient number of men are continuously employed and that all necessary equipment, tools, and parts are immediately available. The supervisor must consider all these factors from the knowledge of his individual personnel, supply, and equipment situation, together with an accurate determination of the extent to which the maintenance task at hand exceeds the inspection requirements if he is to reliably predict the completion time. While this procedure may seem rather involved at first, the new supervisor will find that it is based on sound management principles and that, with experience, his ability to accurately predict time and personnel requirements will speedily improve.

SCHEDULING

If possible, the supervisor should avoid scheduling several jobs that may require identical tools and equipments to be performed at the same time. This often results in confusion and loss of time.

It is also important to schedule activities so that work is accomplished in the proper sequence. This is especially important if men are working on several different phases of the same job.

Time must be allowed in the schedule for assignment of future routine work. This may make it necessary to rearrange the present schedule to insure that special jobs will not interfere with the accomplishment of this work.

ASSIGNMENT OF PERSONNEL

Work assignments should be rotated so that each man will have an opportunity to develop his skills in all phases of the work. When assignments are rotated, the work becomes more interesting for the men. Another good reason for rotating work assignments is that if one highly skilled man performs all the work of a certain type, the supervisor and the shop would be at a great disadvantage in the event the man is transferred from the shop. Less experienced personnel should be assigned to work with him in order to become proficient in his particular skill. Also, in order to broaden his knowledge of his rate, the expert on one job should be rotated to other tasks when there is no immediate need for his particular skill.

Strikers should be assigned to various tasks so that they will acquire experience on all kinds of jobs. A special consideration for the assignment of strikers to jobs is that they should be assigned progressively to jobs of ascending levels of difficulty. A striker may be a useful assistant on a complicated job, but he may not understand what he is doing unless he has worked his way up from basic tasks.

CHECKING PROGRESS AND EVALUATING PROCEDURES

The assignment of work is only the beginning of job processing. The man in charge must know his men and have a fairly good idea of each man's skills and abilities. He must also be aware of each man's knowledge regarding the operation of equipment and the accomplishment of repair work.

The best way in which the supervisor can obtain this knowledge is to make frequent inspections and check the progress of work being performed. In that way he will have a good idea as to which jobs, or which men, will require the most supervision.

When checking the progress of work, the supervisor should make sure that the men are observing proper safety precautions in regard to themselves and the equipment they are operating. In addition, he should see that each man is using the proper tools, and note the quality of the work being performed.

In case of any doubt, he should check to see that his instructions are understood and that the work is being performed correctly. If necessary, he should provide additional instructions to give a better understanding of the job or to improve workmanship. By frequently talking to the men and answering their questions, the supervisor can prevent time and material waste, as could be the case if he were not available to give the correct details.

Complications may develop on some repairs which may require additional planning and revised repair procedures. By observing the progress of the various jobs, and whether they are ahead or behind the planned schedule, the supervisor will be able to change the schedule in order to prevent any major work stoppage.

INSPECTING COMPLETED WORK

When a job has been completed, the man in charge is responsible for inspecting and approving the work. Inspection is necessary to insure that the repair job or the replacement parts will be satisfactory. A thorough inspection normally requires that it be accomplished both visually and by means of measuring instruments. In addition, specific operational tests are performed to check the condition of repaired equipment.

The supervisor is responsible for determining whether the repair job, including replacement parts, meets the following standards:

1. Have the repair parts been correctly installed in accordance with instructions?
2. Is the repaired item or replacement part free from defects in material and workmanship?
3. Have all parts or accessories to the repaired equipment been replaced or reinstalled correctly?

4. Has the proper replacement part been used in making repairs?
5. Has the part or item been properly checked and certified ready for service?

The existence of a properly functioning quality assurance division in no way decreases the responsibility of the shop supervisor for the quality of work accomplished. Since the work was performed by shop personnel under the direct supervision of the senior man, the quality of the work is fundamentally a shop responsibility.

CHANGES AND BULLETINS

Changes and bulletins, are eventually issued to the shop responsible for the subject equipment in the form of maintenance instructions. These instructions prepared by the division officer with the aid of the division or shop supervisor, are an interpretation of the directive. It then becomes the responsibility of the supervisor to instruct and supervise the installation, marking, and recording.

ACQUIRING AND INSTALLING CHANGE KITS

Change kits are not normally ordered directly by the shop concerned. When a directive is received requiring a change kit, maintenance control or designated personnel of the maintenance division, with the assistance of the shop supervisor, if requested, will order the kit.

Installation of change kits is governed by the directive concerning the change or bulletin. Some must be installed immediately in the event safety is involved. Others have specified time periods allowed as determined from the directive. In any case they should be installed as soon as practicable so as to take advantage of the new configuration. The supervisor must insure that workmanship is of the highest caliber, that accepted electrical and electronic installation practices are adhered to, and that detailed instructions, when included, are followed precisely.

MARKING EQUIPMENT AND RECORDING

Change kits are normally ordered and issued against an aircraft bureau number. This means that marking the equipment and keeping complete and up-to-date records is necessary to prevent confusion and loss of time. If correct marking and recording of equipment changes are not kept current, it could affect aircraft availability and scheduling.

Information concerning the type and manner of marking equipments in which a change has been installed is described under the directive heading "identification". In some cases the directive refers to Electronic Material Bulletin 1-54 as the source of information for identification markings. In all cases marking must be accomplished at the time the change has been installed.

If a change is made to plug-in assemblies or subassemblies which are interchangeable between equipments, the identification marking must be applied to the chassis of these assemblies or subassemblies. In addition, this identification marking is also to be placed on the front panel of the equipment.

No markings are to be applied to dust covers, cases, mounting bases, etc., unless a change is made to these specific items. A material marking kit for use by maintenance activities may be obtained through normal supply channels, although most change kits include the necessary equipment for marking.

After the change has been correctly installed and the equipment properly marked, records must be made to reflect the change. Recording is accomplished by the use of history cards, file copies of maintenance instructions (SAMI, CAMI, etc.), and aircraft logbooks.

If the equipment has a history card, this card should be kept current. History cards can be used as a quick reference to equipment configuration; however, if history cards are not required and not used, the file copy of the maintenance instruction will serve the same purpose. When directives require a logbook entry, these entries are recorded by the persons in maintenance control assigned this responsibility.

The main thing for the supervisor to keep in mind is that a record of these changes must be kept, for without them there will be nothing but confusion.

CHAPTER 4

AVIONICS MAINTENANCE SUPERVISION

Avionics maintenance in the Navy is big business and a big problem. It involves thousands of different materials, components, equipments, and systems. More important, it involves trained manpower.

How well any piece of equipment performs depends upon the ability of the men who operate and maintain it. If these men cannot maintain the equipment at the desired level of operation, its usefulness descends toward and often approaches zero. Malfunctions in avionics equipment are hazardous. They are not only hazardous to flight personnel, but can also result in the damage or destruction of valuable aircraft.

Maintenance should be preventive in nature, where potential failures are detected and corrected before they have an opportunity to develop into complete equipment breakdown. Timely replacement of parts exhibiting evidence of failure will help prevent breakdown and will lengthen the useful life of the equipment or system.

EVALUATING DISCREPANCIES

Since it is impossible to prevent all equipment failures or malfunctions through preventive maintenance, there is a need for corrective maintenance. This type of maintenance requires the application of intelligent evaluation and troubleshooting procedures. In order that maximum efficiency be realized, it is of utmost importance that evaluation of discrepencies be carried out in logical sequence. When the malfunction occurs during flight, this should begin with a debriefing of the flight crew.

DEBRIEFING FLIGHT CREWS

When operating complex weapons systems an operator-maintenance debriefing procedure is necessary. A detailed debriefing of the flight crews' experiences and a complete analysis of the reported discrepancies are desired. Many man-hours can be saved by knowing what the trouble is and what is required to correct it before scheduling any maintenance action.

The physical location for the debriefing will vary and is usually designated by maintenance control. For squadrons operating ashore, debriefing can be accomplished in the "line shack" during or immediately after the time the flight crew completes the "yellow sheet." Sometimes the location of the fire control shop will be such that it can be used to better advantage. Onboard ship the readyroom is normally used for this purpose since it is the place from which squadron operations are directed.

In order to obtain the most from the debriefing, the supervisor should insure that it is conducted in an efficient manner by the most experienced and best qualified technicians.

OPERATIONAL CHECKS

An operational check of a system can aid in analyzing a discrepancy and will often pinpoint the trouble to a particular unit. In some cases, it might disclose improper operating procedures—especially in newer type equipment.

Reliance alone on visual observation to judge the range capability and data accuracy of radar systems has been found to be so inaccurate as to be completely valueless. Numerous tests made on radar equipments in the field strongly emphasize this fact. In one instance, the performance of approximately 100 different systems was carefully measured with test equipment of known accuracy. In each case, the system under test was considered to be in normal operating condition by the radar personnel concerned.

The results of these tests revealed that on the average the maximum effective range of the radar equipments under test was only ONE-HALF the maximum range possible if the equipments had been operating at peak efficiency. In fact, five radar sets were found to be operating at less than 10 percent of their possible maximum range, which means, in effect, that these radars were protecting only 1 percent of their assigned tactical areas. Since such poor performance as demonstrated by these tests may have serious wartime consequences, it should readily be seen that performance testing is of the utmost importance in radar work.

Investigation of the cause of this unsatisfactory situation showed that many technicians are not sufficiently familiar with the techniques and procedures necessary to test microwave-radar systems properly. The use of portable test equipment, built-in meters, and special test equipment installed in some types of aircraft will aid in making a performance test of the system in the aircraft.

Minimum Performance Testing

Along with other maintenance information, minimum performance testing is covered in detail in the Service Instruction Manual for each particular type equipment. This information has been written to enable the technician to make an intelligent evaluation of the operating capabilities of the equipment; at the same time the data serve as a gage for the measurement of equipment efficiency. The standards are designed to insure that equipments operate at maximum efficiency at all times, and to reveal any change from this optimum performance, thus indicating the need for corrective measures. The information presented in these manuals gives the technician a step-by-step performance check with all the test connections and test equipment clearly indicated for each step. Minimum performance tests are also discussed in chapter 9 of this manual.

Isolation of Troubles

Troubleshooting of equipment as complex as the average radar set must be conducted in an orderly and systematic manner, if the cause of trouble is to be isolated and corrected as quickly as possible. In most cases, the application of fundamental radio principles and basic electronic circuits will contribute greatly in solving the problems encountered in the day-to-day operation and maintenance of radar equipment. The supervisor should have a prescribed procedure for the technician to follow in checking a discrepancy. He should also study and constantly refer to the available publications pertaining to the equipments used by his activity and be ready to answer any questions about the equipments or outline the various steps necessary to correct any troubles.

BUILT-IN TEST (BIT).–In some of the later equipments special BIT circuits will provide the technician with an indication of system operation. When the BIT is used in performance testing, the operator must be able to interpret the results as read out on the radar indicator. With the aid of an overlay pattern or etched markings on the indicator face and other meter indications, the operator can determine if the system is operating properly and what action will be necessary to take, if any. This type testing requires that maintenance personnel have a THOROUGH knowledge of the entire system operation and be able to evaluate the test indications as presented on the radarscope and other indicators.

An advantage of the BIT is that the operator may test the system in flight, and provide information during the debriefing concerning special symptoms of troubles that may occur only when airborne.

NOTE: The BIT will check the entire system and indicate if the equipment is operating at an acceptable level. However, this cannot be used to replace the minimum performance checks as described in the Service Instruction Manuals.

SEMIAUTOMATIC CHECKOUT EQUIPMENT (SACE).–Some aircraft with the most advanced and completely integrated electronic systems would take excessively long periods of time to check out or test. In some of these aircraft a system of punched, programmed tapes are used to make a "GO-NO GO" check of system operation. One of these types is SACE which is used in testing of system equipment in the A-6A. In making a test of the performance of an installed system using this equipment, the operator is required to evaluate parts of the readout; other portions of the test will be automatic or semiautomatic and the test can be so selected to be automatically stopped when an error in the test readout occurs. This equipment also can prepare a permanent record of the test results.

PERFORMANCE RECORDS.–The value of performance data records is demonstrated in a number of ways. Comparison of data taken on particular equipments at different times reveals any slow, progressive drifts that may be too small to be detected in any one test. While the week-to-week changes may be slight, they should be followed carefully so that necessary replacements or repairs may be made before the margin of performance limits is reached. Any marked variation must be regarded as abnormal, and should be investigated immediately. Another advantage in keeping systematic records of performance and servicing data is that maintenance personnel develop a more rapid familiarization with the equipment involved. The accumulated experience contained in the records furnishes a guide to swift and accurate troubleshooting.

CORRECTING DISCREPANCIES

Isolating a trouble to a particular unit (assembly) or subassembly by one or more of the methods previously described is only a small part of the entire solution of the problem.

The main and pressing objective of discrepancy correction is that of getting the aircraft back in commission the quickest way possible. The period of time required to accomplish this objective will be determined by several factors. The seriousness of the discrepancy, availability of spare parts, and the workload carried at the time are all factors affecting aircraft downtime. One of the most important factors is the decision made by the supervisor and his assigned crew leaders as to the exact method used to solve the problem. One of the following questions should hold the clue:

1. Can the trouble be adjusted out by some portion of alinement?
2. Can the needed repair be accomplished in the aircraft?
3. Is it necessary (or better) to remove and repair a unit or part and return it to the aircraft?
4. Is replacement of a unit or part required?

ADJUSTMENTS

Many times an adjustment or partial alinement will correct the discrepancy, but for the day-to-day line maintenance problems avoid becoming involved in long drawn-out alinement procedures, if possible. This is because of the tendency of maintenance crews to hurry when attempting long alinement while being pressed for time. Excessive speed usually results in poor alinement or sometimes in misalinement and no progress will be accomplished.

This is not meant to imply that necessary alinements can be omitted. There will be times when a complete system alinement will be necessary to return the equipment to efficient operation. This will be a decision for the crew leader or supervisor.

In the event that adjustment or alinement is required, the currently approved alinement procedures, as described in the appropriate equipment manual, must be used. Unless the adjustments are relatively few and simple, reliance on memory for an alinement is not a good practice since it will probably result in a waste of time and poor alinement. A misalinement will likely be the end result and the entire system will have to be alined a second time.

Some adjustments are critical and difficult to make. Others are simple and are provided with a large range in which to work, but the ability to make an adjustment or perform an alinement properly improves with experience. Each technician should be urged to make a concentrated effort in this area, because it will mean the difference between average or marginal operation and peak performance.

REPAIRS AND REPLACEMENTS

It is good practice to do as much as possible toward correcting equipment discrepancies in the aircraft or to remove, repair, and return a unit to the aircraft to avoid major adjustments or unit replacements that would disturb the system alinement. This of course will be dependent on the extent of the repair, time allowed, and availability of replacement parts. There is no need to replace a major unit if a simple tube or module replacement and a few minor adjustments will eliminate the problem. For instance, assume that a trouble has been determined to be in the synchronizer. The decision to replace the entire unit instead of replacing a subassembly could result in an extension of aircraft downtime because of long alinement time. This choice will depend on the particular function of the subassembly to be replaced. Either of these two parts would correct the discrepancy, but as any radar technician knows the replacement of a major unit usually requires extensive time-consuming realinement procedures. In the case mentioned, the synchronizer presently installed is alined to the system so the replacement of a subassembly which normally will require less time spent in realinement might be the better of the two alternatives.

In any event the main problem will have been solved and the aircraft is back in commission. If replacement was the solution to the problem, then there is now a down piece of equipment in the shop. The next step is to further isolate and identify the particular component or group of components which are the cause of the trouble. If the cause is not immediately apparent after removal from the aircraft, then disassembly of the unit or subunit, to some extent, will be necessary. A more detailed procedure must be followed to isolate and repair or replace the component responsible for the failure.

The supervisor must make sure that detailed trouble isolation procedures are in accordance with applicable current Service Instruction Manuals for the equipment being repaired.

Screening Defective Materials

At this point a very important step should take place. The supervisor, or his designated representative, must carefully check all defective materials and determine the possibility of repair at the local level before turning them in to an already heavily laden supply system. In fact, Naval Air Systems Command and NavAirLant have a maximum repair policy that has been in effect for several years. Some activities have taken the program to heart and are working efficiently, while others have been slow to accept the program, or support it only superficially.

The policy of the maximum repair concept is that "avionics material shall be repaired at the lowest possible maintenance level." If you want to measure your own performance, count the number of units sent to screening as prospective "RB." As a general rule, only crash damaged equipment should end up in screening (hermetically sealed and potted units excepted).

Maximum repair is not just a professional requirement imposed by higher command. It is an economic necessity, and careful screening at the local level will prevent these defective materials from clogging the supply system.

Tube Replacement

Although present equipment design is such that the electron tube is being used less frequently, there are still many systems in operation which utilize a great number of tubes. In some of these systems, electron tubes are responsible for a large percentage of troubles that occur. However, if a particular system contains a great number of tubes, it is obviously impractical, and not good policy, to attemp to locate faults by general tube checking. Only after a fault has been traced to a particular stage should any tubes be tested. In many radar circuits the testing of tubes is futile and the technician must resort to tube substitution. The substituted tube must have been previously checked in a properly operating circuit in order to be sure of its condition.

Normally, after tube replacement some minor adjustment will be required, but before any adjustment is made the positions of the controls should be recorded or marked so they can be returned to their original position in case the adjustment does not correct the abnormal condition. The original tube if not defective should also be returned to its position in the circuit. In many high frequency circuits the interelectrode capacitance of the tube is a significant portion of the tuned circuit; thus if too many tube substitutions are made, the unit may become misalined.

Voltage Measurements

Since most troubles encountered in equipments and systems either result from abnormal voltages or produce abnormal voltages, voltage measurements are considered an indispensable aid in locating troubles. Testing techniques that utilize voltage measurements also have the advantage that circuit operation is not interrupted. Point-to-point voltage measurement charts which contain the normal operating voltages encountered in the various stages of the equipment are available to the technician. These voltages are usually measured between the indicated points and ground unless otherwise stated.

When voltage measurements are taken, it is considered good practice to set the voltmeter on the highest range initially so that an excessive voltage in a circuit will not damage the meter. To obtain increased accuracy, the voltmeter may then be set to the designated range for the proper comparison with the representative value given in the voltage charts.

If the internal resistance of the voltmeter and multiplier is approximately comparable in value to the resistance of the circuit under test, it will indicate a considerably lower voltage than the actual voltage present when the meter is removed from the circuit. The sensitivity (in ohms-per-volt) of the voltmeter used to prepare the voltage chart is always given on the charts. Therefore, if a meter of a similar sensitivity is available it should be used so that the effects of loading will not have to be considered.

When checking voltages, it is important to remember that a voltage reading can be obtained across a resistance, even if the resistance is open. The resistance of the meter and of the multipliers forms a circuit resistance when the meter prods are placed across the open resistance. Thus the voltage across the component may appear to be normal when the meter is connected, and abnormal when it is disconnected. If the voltages appear normal on a faulty stage, the next step would be to perform a resistance check of that stage.

NOTE: Certain precautions are presented in Basic Electricity, NavPers 10086-B, as general safety measures pertinent to the measurement of voltages. Supervisors should ascertain that these precautions are adhered to by all personnel who are responsible for the maintenance of electronic equipment.

Resistance Measurements

Defective components can usually be quickly located by measurement of the d-c resistance between various points in the circuit and a reference point or points (usually ground). This is true because a fault will generally produce a change in resistance values. Point-to-point resistance charts can be used advantageously at this time. The values given, unless otherwise stated, are measured between the indicated points and ground.

Before making resistance measurements, the technician should make sure that the power to the equipment under test has been turned off. Since an ohmmeter is essentially a low-range voltmeter and a battery, an ohmmeter connected to a circuit which already has voltages in it may be seriously harmed. The pointer may be deflected off scale, and the meter movement may be permanently damaged.

Filter capacitors must be discharged before making resistance measurements. This is extremely important when testing power supplies that are disconnected from their loads. If a capacitor discharges through the meter, the surge may burn out the meter movement. Furthermore, contact with a circuit containing a charged capacitor may endanger the life of the person making the test.

Waveform Comparison

The measurement and comparison of waveforms are considered to be very important parts of the circuit analysis used in the troubleshooting. In some circuits (for example, pulse circuits) waveform analysis is indispensable. Waveforms may be observed at test points, shown in the waveform charts which are part of the maintenance literature for the equipment. It should be noted that the waveforms given in the instruction books are often idealized and do not show some of the details which are normally present when the actual waveform is displayed on an oscilloscope.

By comparing the observed waveform with the reference waveform, faults can be localized rapidly. A departure from the normal waveform indicates a fault that is located between the point where the waveform is last seen to be normal and the point where it is observed to be abnormal. (For example, if a waveform is observed to be normal at the grid circuit and abnormal at the plate circuit of the same stage, this indicates that the trouble lies in that stage or possibly the input of the following stage.)

When waveforms associated with a multivibrator, a blocking oscillator, or a similar circuit are observed to be abnormal, replace the associated tube before making further tests. If the replacement tube does not provide the correct waveform, reinsert the orginal tube.

If there is no trouble present in an equipment or system, a waveform observed at a point in the equipment should closely resemble the reference waveform given for that test point. The reference waveforms supplied with maintenance literature are the criteria of proper equipment performance. However, test equipment characteristics or usage can cause distortion of the observed waveform, even though the equipment or system is operating normally. Several of the most common causes of these conditions are summarized as follows:

1. The leads of the test oscilloscope may not be placed in the same manner as those preparing the reference waveforms, or the lead lengths may differ considerably. This is particularly significant in the case of shielded test leads, where the capacitance per unit length is a factor.
2. A type of test oscilloscope having different valves of input impedance, different sweep durations, or different frequency response may have been used.
3. The equipment operating (and servicing) controls may not have settings identical to those used when the reference waveforms were prepared. This condition is normally to be expected when servicing adjustments are made in terms of their effect on the shape and amplitude of an observed waveform.
4. The vertical or horizontal amplitudes of the reference and test patterns may not be proportional. This will produce apparent differences between the waveforms when actually there is no difference.

Whether or not a minor waveform discrepancy may be disregarded depends upon the type of circuit being traced. A minor discrepancy is not regarded as significant unless the nature of the discrepancy indicates faulty operation of the equipment. In general, time should not be wasted in searching for faults when relatively minor differences are detected between the reference waveforms and those obtained by test.

Modular Units

The demand for small, maintainable circuitry in military equipment has led to many different construction techniques. One of the most popular is modular construction. Since modular assemblies incorporate several subminiaturized features not found in conventional equipment, some specialized knowledge and tools are required for efficient repair and maintenance.

A few definitions are helpful in understanding the terms involved. A module is defined as "a unit or standard of measurement; a fixed dimension." A modular assembly has outline dimensions which are multiples of a module. An equipment which consists of replaceable assemblies (any type) is said to be of unitized construction. Modular construction then is a type of unitized construction consisting predominantly of modular assemblies.

For example, think of a carton of cigarettes. If each pack were a modular assembly, the carton would be an equipment of modular construction. Notice that the packs can be arranged differently without changing the outside dimensions of the carton. Although the cigarette packs are all the same size, the assemblies in many equipments are not.

The original concept of many modular assemblies was that they should not be maintained in the field. The intention was to replace the assembly and ship it back to some repair facility. As assemblies became more complex, the point was soon reached where the extensive supply system required for the replacement concept was too costly. Many equipments built during this initial stage were potted with some special ingredient to discourage maintenance personnel from tampering with the insides of a "black box."

When the Navy reassessed this concept, realizing that the Fleet must maintain everything it could, most of the equipment manufacterers began to make components accessible. However, many technicians are still convinced that modular assemblies are impossible to repair. This conviction may stem from a lack of experience in working with the printed circuits and the other components in modular assemblies. While it is true that special tools and techniques are required, it is also true that satisfactory repairs can be made to any printed circuit by using a little care and commonsense. Actually, with a little experience, repairs can be made as easily as in conventional assemblies–often more easily because of improved accessibility.

Component Location

One of the time-consuming elements of troubleshooting is the identification of specific components. In conventionally wired equipment, components are not always easy to locate, even the circuitry in the chassis can become confusing since related components are often positioned in decentralized areas of the chassis.

In equipment which includes printed circuit boards, identification of circuitry and components may be relatively simple. This type of circuit construction allows uniform placement of components and complete sectionalization of related circuitry. Just a quick, onceover glance of such circuitry is often all that a technician requires to formulate the overall layout of the chassis in his mind and quickly focus his attention on the area of particular concern.

Many of the commercial manufacturers have developed methods of quick identification. One of the most common ways is to impose a grid over a drawing of the board, and then furnish a table which lists the part location. Another technique is to number points of interest on the schematic, then provide a pictorial guide to locate the points on the board.

Circuit tracing of the printed wiring board may be simpler than that of conventional wiring, due to increased uniformity. If the wiring board is translucent, a 60-watt light bulb placed underneath the side being traced will facilitate circuit tracing. Test points can be located in this manner without viewing both sides of the board.

Resistance or continuity measurements of coils-resistors, and some capacitors can be made from the component side of the board. In some cases, a magnifying glass will help in locating very small breaks in the wiring. Voltage measurements can be made on either side of the board. However, a needlepoint probe is needed to penetrate the protective coating on the wiring. Hairline cracks can be located by making continuity checks.

Modular Assembly Precautions

A number of general precautions are necessary when working with modular assemblies. Supervisory personnel should take steps to insure that the technicians in their shop or maintenance crew know and understand the rules set forth in the following paragraphs:

1. Observe power supply polarities when troubleshooting the circuits of modular assemblies containing transistors, or other semiconductors. Such parts are polarity- and voltage-sensitive. Reversing the plate voltage polarity of a triode vacuum tube will keep the stage from operating, but generally will not injure the tube. However, reversing the voltage applied to a transistor, or other semiconductor, will ruin it very quickly.

Since transistors and similar components require different power supply connections, the personnel who work with these parts must always be alert in connecting test equipment. Make sure that the correct polarity and range are observed. Recheck your work before turning on the power—the wrong polarity will destroy the part.

2. Avoid applying a-c power operated test equipment or soldering iron without first making certain that powerline leakage current is not excessive. Use of an isolation transformer is a good precaution to employ with all test equipment and soldering irons operated on a-c power, unless it has been determined that the equipment contains a transformer in its power supply or shows no current leakage. With all test equipment (whether transformer-operated or not), it is good practice to connect a common ground lead first from the ground of the circuit to be tested, and then to the test equipment ground.

3. Avoid application of too high a pulse from test equipment. The safest procedure is to start with a low output signal setting, and then proceed to apply the required signal levels. Be sure that the signal applied is below the rating given for the circuit under test. Relatively high current transients can occur when test equipment is connected to a circuit where low-impedance paths exist.

4. Avoid moving loose connections, disconnecting parts, inserting or removing transistors or similar components, and changing modular units while the equipment power is on or while the circuit is under test. Moving a loose connection, or any of the actions mentioned, will cause an inductive kickback. This can be prevented by being sure that all the parts in the circuits are secure before starting the test or turning on the equipment power. Be sure to remove all possible capacitance charges from parts and test equipment before applying them to a modular assembly. When changing modular assemblies, be sure the equipment power is off.

INSPECTING REPAIRS AND EVALUATING COMPLETED MAINTENANCE ACTION FORMS (MAF'S)

The final phase of the maintenance task includes the inspection of the repaired equipment and the evaluation of the completed Maintenance Action Form (MAF). During the inspection, all maintenance performed in connection with the MAF must be included. The MAF may have called for work to be performed on one item in the system, but in the course of troubleshooting, other items in the system may have been removed and reinstalled. Every item that has been replaced, removed, reinstalled, adjusted, or otherwise worked on in connection with the maintenance task must be included in the final inspection.

When performing an inspection, serious thought and consideration must be exercised in regard to where the man that performed the work may have left tools or other materials. Objects left adrift in aircraft become lethal weapons during catapult launchings and arrested landings. When making the final inspections, do not let your good judgment be altered by personnel considerations, operational commitments, or personnel trying to hurry the job. Know the correct maintenance procedures and insist that they be followed.

The final inspection also includes an evaluation of the completed MAF. The supervisor or his designated representative must review and evaluate the completed form(s). He should insure that all applicable blocks are filled in correctly and legibly. The importance of using the correct codes when filling in the MAF cannot be stressed enough. Having the correct codes, part numbers, work unit codes, serial numbers, etc., is not only important for your future reference, but is important when these MAF's are processed and sent in for use by the Navy. The supervisor should make sure that all the required information is recorded in the Work Center Register before turning in for processing.

The supervisor should also insure that the person completing the work and the inspector have signed the MAF and that Maintenance Control has been notified that it is completed.

DISCREPANCY TRENDS

By careful and continuous reference to the daily discrepancy reports, Work Center Registers, etc., a definite trend in discrepancies may be detected. Detection in itself is not difficult.

The big problem is reducing these indications to basic causes or reasons for such trends. Sometimes they can be traced to improper maintenance procedures such as misalinement caused by maintenance personnel not adhering to the specifically outlined procedures. Perhaps the problem will be revealed by an investigation of the test equipment being used. Such an investigation may disclose improper operation of test equipment or that the error tolerances have been exceed. At other times an equipment deficiency, especially in newer types of equipment, can be "pinned down" as the reason. If there should be an equipment deficiency, the supervisor should make sure that an Unsatisfactory Material/Condition Report (UR) is completed and forwarded so that corrective action may be taken after further investigation by the Naval Air System Command. No matter what the cause, an analysis of the problem is required when a trend in discrepancies is noted.

ANALYZING DEFICIENCIES

In order to properly analyze any problem the supervisor must have a thorough understanding of the operation of the equipment being maintained and of the test equipments necessary to maintain it. Armed with this information and with a sincere and conscientious approach, almost any maintenance problem can be deliberately and systematically resolved in reasonable time. Most of the difficult and many of the seemingly impossible problems have been solved by careful and painstaking testing and recording of indications obtained through voltage and resistance checks, waveform comparisons, and the application of basic theories. The more difficult the problem the more exacting must be applied procedures and tests.

The major contribution to analyzing a problem is a clear and orderly thought process. The supervisor must provide this ingredient since test equipment, charts, and tables will only contribute the necessary material to be used in these thoughts.

While the supervisor is involved in analyzing these deficiencies, he may discover a better method of alinement or find a potential trouble spot in the equipment for which he may help find a solution by making known a suggestion to remedy the situation. By so doing he will be aiding in the entire program of improving productivity by saving man-hours and material. This process is known as Value Analysis in Maintenance Operations (VAMO).

Value Analysis in Maintenance Operation

Value Analysis in Maintenance Operations (VAMO) can be defined as a systematic and continuing evaluation of those factors affecting the efficient maintenance of a component, equipment or system. It encompasses functional as well as engineering design standardization, and reliability as well as ease and frequency of maintenance operations. The maintenance supervisor accepts his responsibility to keep the equipment in readiness and conscientiously attempts to "keep them flying." He will not knowingly compromise the functioning of equipment under his jurisdiction even though occasionally he must ground aircraft because of insufficient time to complete a job. When an aircraft is grounded it affects the fulfillment of the Navy's mission. Value maintenance, if objectively and actively pursued, can result in increased maintenance efficiency by saving man-hours of shop time and can thereby result in fewer grounded aircraft.

Through value analysis, and through human and design engineering, efforts are continually being made to build maintainability and reliability into all new components, equipments, and systems. This is fine, but it is not enough—the one missing ingredient is the knowledge of how a specific component, equipment or system performs under actual operating conditions—and what to do to improve this performance. This is where the maintenance supervisor has the "front seat." He is in a position to get first-hand information based on operating experience. He is able to observe the degree of maintainability and reliability designed into the equipment. If he is satisfied to accumulate such data only for his own or his immediate associates' use and does not bother to pass it along, he is missing a great opportunity to share in the building of the Navy's effectiveness.

Remember, you are a Navy maintenance supervisor, and you earned your rating by having the ability and intelligence to do the job. Maintenance in many respects is just as important in the overall picture as the original design. Any equipment that requires repeated maintenance as well as frequent downtime for routine inspection is not serving the Navy to best advantage. Such equipment presents a logistic problem which costs money. You, as a maintenance supervisor, can often remedy such situations simply by sharing your time saving ideas. Remember, constructive criticism and suggestions are always welcome. The few minutes your method saves may seem insignificant; but if others are also able to save those minutes by following your shortcuts, the Navy will be able to measure its savings in hours or days.

Consider evaluating your equipment for places where improvements can be made. There are many potential trouble-spots that rate particular attention. A few examples of the kinds of questions maintenance men should ask and items they should keep in mind are listed below for future reference. This is not an all-inclusive list—it never could be, because new equipment and new equipment locations will always present new problems. VAMO is a continuing challenge to your ingenuity as a maintenance supervisor.

1. Are controls and adjustments located so that they can be seen readily and reached without difficulty? You should not be expected to disassemble or remove any part of an equipment for access during maintenance.
2. When replacing a component, you should not have to remove other components.
3. Connecting cables should be long enough to permit withdrawing the equipment for access to adjustments without breaking the electrical connections. In modulized equipment a test (extension) cable should be provided, thus permitting the unit to be serviced without demounting the entire assembly.
4. Be especially careful to look for unkeyed connectors having a symmetrical pin arrangement that could be misconnected inadvertently. Also look for places where the wrong connector could be inserted because of its similarity in size, etc., to the correct one.
5. Look for operations that are hazardous (either from an electrical shock or physical standpoint). It takes a lot longer to make an adjustment in a cramped physical position than when the control is located at a convenient level.
6. Quick, easily identifiable component nomenclature is always a must. Minutes of search time can be saved.

In summary, remember that any unusually difficult operation should be analyzed for a simpler solution. Once you have solved the problem, share your solution with others.

Although the Navy does not have a specific, formalized program of VAMO, it utilizes value analysis principles daily. The Material Reliability Program is an excellent example of an important phase of value maintenance. This program, in part, utilizes the Failure, Unsatisfactory Material/Condition Report (UR). Operating activities are responsible for prompt submission of FUR's. The maintenance supervisor should make every effort to determine the precise causes of component failures or malfunctions, particularly those involving aircraft accidents. If this cannot be done locally, priority disassembly and inspection reports or laboratory analysis reports, as appropriate, should be requested.

Every time you make out a FUR, you are setting in motion a far-reaching program for the evaluation of faults, malfunctions or failures of materials. These reports must be analyzed; statistics must be collected and correlated; and the results must be evaluated and fed back to personnel who are responsible for seeing that any needed corrective action is taken. The results of the FUR programs are commendable. Changes resulting from these reports release thousands of maintenance man-hours for other tasks which help to keep our aircraft in the air and may even save lives by eliminating dangerous conditions.

The maintenance supervisor's contribution to the Value Maintenance operation should not be limited to submitting FUR's. When he discovers a design deficiency, publications error, or improper supply parts or FSN's he should take action by one of two methods. First, he can request his division officer to initiate an official letter, via the chain of command, to the Naval Air Systems Command. The other method is to ask for the assistance of a NAESU field engineer. This engineer will analyze the problem and prepare and forward a technical report to NAESU Headquarters. The report will be reviewed by NAESU and forwarded to the Bureau and others, with recommendations for corrective action. This method will sometimes bring corrective action much sooner than the first.

UNSATISFACTORY MATERIAL/ CONDITION REPORT (UR) NAVAIR FORM 13070/5

The Unsatisfactory Material/Condition report is a supporting document of the Maintenance Data Collection Subsystem of the Aviation 3-M program. This document is intended to provide a method for the expeditious reporting of special and safety conditions. The use of this form provides a direct narrative link between the user and the supporting activity. Therefore, it should be used when prompt corrective action is required and/or amplifying details are necessary beyond that provided by means of routing 3-M documentation.

The Naval Air Systems Command Unsatisfactory Material/Condition Reporting System is designed to provide rapid collection and dissemination of Unsatisfactory Material/Condition reports to cognizant governmental and industrial activities responsible for providing prompt corrective action in the case of serious material discrepancies and operational maintenance problems. The report is also used to assist in the replacement or correction of defective new material furnished to the Navy. In addition, this system also utilizes the UR form for reporting errors and omissions and for making recommended corrections to publications. All supervisors are directed to give their fullest support to the UR system, not only by strict adherence to the detailed instructions for submitting reports, but also by exercising a conscientious effort toward achieving program objectives. In this regard, the assignment of competent personnel to prepare and review UR's is mandatory.

Preparation

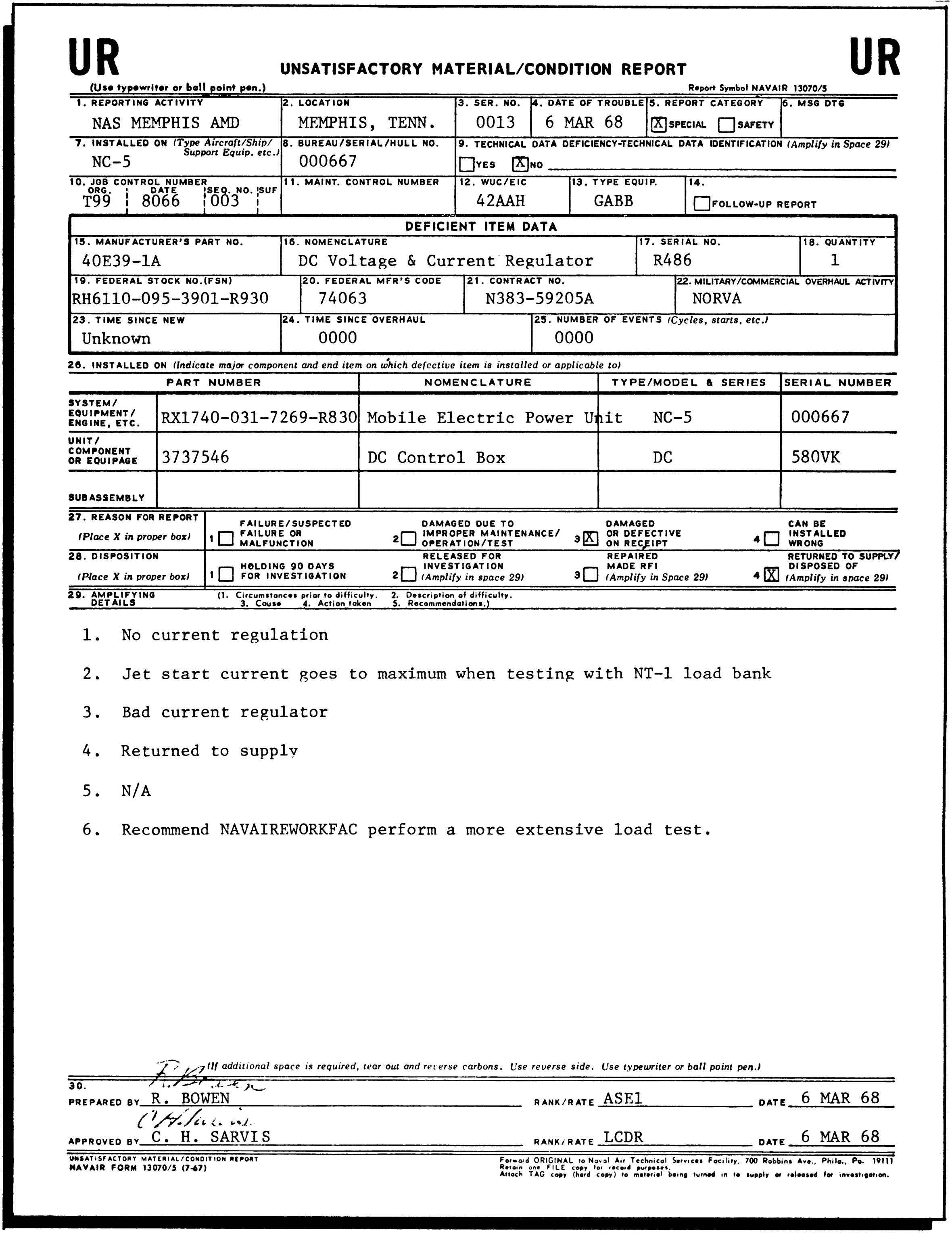
The UR is provided in a carbon backed four-page set. The original of the UR is forwarded to the Naval Air Technical Services Facility, 700 Robbins Ave., Philadelphia, Pennsylvania, 19111. The FILE copy is to be retained by the originating activity for record purposes. The TAG copy of the special UR must be placed in the return material document envelope and attached to the material being turned into supply or released for investigation. In the event that the material is not turned in to supply or released for investigation, the TAG copy should be discarded and the envelope retained for reuse. The top sheet of the UR set provides detailed instructions for preparation of the UR form. READ ALL INSTRUCTIONS ON THE COVER SHEET BEFORE FILLING IN THE REPORT. Refer to the latest NavAir Instructions concerning maintenance management of aviation material for detailed reporting procedures. UR reports on classified contracts and equipment must be classified in accordance with the latest Department of the Navy Security Manual for Classified Information. Use a typewriter or ballpoint pen to insure that all copies are legible. Figure 4-1 is a typical example of a completed UR report.

The information should be as complete and accurate as possible in order to provide all technical data necessary for determining appropriate corrective action. Photographs (5 copies) should be furnished when they will assist in showing areas of damage or deficiency. Photographs should be of a glossy finish and preferably 8 x 10 inches in size. When the descrepant item has been released for priority investigation, the activity/contractor to which the material was forwarded should be so noted. Submittal of drawings or schematic diagrams encouraged to assist in clarifying the problem or recommending corrective action. If additional space is required for narrative information, tear out and reverse carbons and continue on the reverse side.

DEVELOPMENT OF INSPECTION PROCEDURES

In developing good inspection procedures, it is necessary to first establish an acceptable quality level of work, keeping in mind that safety must always come first. Next a continuing procedure for analyzing discrepancy trends must be created; records must be kept; and followup action must be provided to stimulate improved workmanship. The crew's thinking must be influenced so as to incorporate principles of quality control in each step of the job. Technicians should be encouraged to help each other by double-checking each other's work as they go along. Any job is properly accomplished by first delegating it to those who can and should be doing it; therefore, the best qualified technicians must be assigned to perform the inspection. Insure that these men have all the specifications and records needed to perform the inspections. Every man in the crew must understand that an inspection is not to fix blame or to comply with a requirement, but to save aircraft and lives and to provide the best operating equipment possible.

The morale and physical condition of the crew are equally important as their technical ability. If a man works beyond his physical capability, he does not take time to do each job with painstaking care. Morale, which is a product of leadership, plays a vastly important role in the maintenance program since it can so adversely affect the flight support effort. This in turn will deny a good safety environment regardless of the fact that the maintenance personnel are well trained. The supervisor must set a good example because people try to imitate or take for their own those qualities they admire in those they identify as their leaders. If the



UR UNSATISFACTORY MATERIAL/CONDITION REPORT **UR**

(Use typewriter or ball point pen.) Report Symbol NAVAIR 13070/5

1. REPORTING ACTIVITY NAS MEMPHIS AMD	2. LOCATION MEMPHIS, TENN.	3. SER. NO. 0013	4. DATE OF TROUBLE 6 MAR 68	5. REPORT CATEGORY ☒ SPECIAL ☐ SAFETY	6. MSG DTG

7. INSTALLED ON (Type Aircraft/Ship/ Support Equip. etc.) NC-5	8. BUREAU/SERIAL/HULL NO. 000667	9. TECHNICAL DATA DEFICIENCY-TECHNICAL DATA IDENTIFICATION (Amplify in Space 29) ☐ YES ☒ NO

10. JOB CONTROL NUMBER ORG. T99 DATE 8066 SEQ. NO. 003 SUF	11. MAINT. CONTROL NUMBER	12. WUC/EIC 42AAH	13. TYPE EQUIP. GABB	14. ☐ FOLLOW-UP REPORT

DEFICIENT ITEM DATA

15. MANUFACTURER'S PART NO. 40E39-1A	16. NOMENCLATURE DC Voltage & Current Regulator	17. SERIAL NO. R486	18. QUANTITY 1
19. FEDERAL STOCK NO. (FSN) RH6110-095-3901-R930	20. FEDERAL MFR'S CODE 74063	21. CONTRACT NO. N383-59205A	22. MILITARY/COMMERCIAL OVERHAUL ACTIVITY NORVA
23. TIME SINCE NEW Unknown	24. TIME SINCE OVERHAUL 0000	25. NUMBER OF EVENTS (Cycles, starts, etc.) 0000	

26. INSTALLED ON (Indicate major component and end item on which defective item is installed or applicable to)

	PART NUMBER	NOMENCLATURE	TYPE/MODEL & SERIES	SERIAL NUMBER
SYSTEM/ EQUIPMENT/ ENGINE, ETC.	RX1740-031-7269-R830	Mobile Electric Power Unit	NC-5	000667
UNIT/ COMPONENT OR EQUIPAGE	3737546	DC Control Box	DC	580VK
SUBASSEMBLY				

27. REASON FOR REPORT (Place X in proper box) 1 ☐ FAILURE/SUSPECTED FAILURE OR MALFUNCTION 2 ☐ DAMAGED DUE TO IMPROPER MAINTENANCE/ OPERATION/TEST 3 ☒ DAMAGED OR DEFECTIVE ON RECEIPT 4 ☐ CAN BE INSTALLED WRONG

28. DISPOSITION (Place X in proper box) 1 ☐ HOLDING 90 DAYS FOR INVESTIGATION 2 ☐ RELEASED FOR INVESTIGATION (Amplify in space 29) 3 ☐ REPAIRED MADE RFI (Amplify in Space 29) 4 ☒ RETURNED TO SUPPLY/ DISPOSED OF (Amplify in space 29)

29. AMPLIFYING DETAILS (1. Circumstances prior to difficulty. 2. Description of difficulty. 3. Cause 4. Action taken 5. Recommendations.)

1. No current regulation
2. Jet start current goes to maximum when testing with NT-1 load bank
3. Bad current regulator
4. Returned to supply
5. N/A
6. Recommend NAVAIREWORKFAC perform a more extensive load test.

(If additional space is required, tear out and reverse carbons. Use reverse side. Use typewriter or ball point pen.)

30. PREPARED BY R. BOWEN RANK/RATE ASE1 DATE 6 MAR 68

APPROVED BY C. H. SARVIS RANK/RATE LCDR DATE 6 MAR 68

UNSATISFACTORY MATERIAL/CONDITION REPORT
NAVAIR FORM 13070/5 (7-67)

Forward ORIGINAL to Naval Air Technical Services Facility, 700 Robbins Ave., Phila., Pa. 19111
Retain one FILE copy for record purposes.
Attach TAG copy (hard copy) to material being turned in to supply or released for investigation.

AQ. 361

Figure 4-1. –Unsatisfactory Material/Condition Report (UR) NavAir 13070/5

leaders are respected and admired as good, aggressive, professionals who create by their interest and actions a good attitude toward flying and safety, then the maintenance program will be good.

With good leadership we are assured of high morale. This combined with good maintenance training and good quality control will insure good maintenance and flight support.

ENVIRONMENTAL EFFECTS

Although the need for a high degree of reliability in military electronic equipment has remained relatively constant since the start of World War II, the difficulty of attaining this reliability has increased many times over. The electronic equipments presently utilized for military purposes are a far cry from those commonly used 15 years ago. The continually increasing complexity of electronic equipments and the subjection of these equipments to more and more rigorous environmental conditions are among the chief causes of equipment failure. In addition, the component parts failure rates that were tolerable in the relatively simple communciations equipments of the late 1930's are completely intolerable in the complex electronic system now used or contemplated for search, navigation, fire control, communications, and other functions in military operation. For these reasons electronics technicians must be able to anticipate and evaluate the effects that environmental conditions may have on the equipments for which they are responsible.

The environmental factors that must be considered include temperature, humidity, corrosive atmospheres, abrasive conditions, pressure, shock, vibration, and acceleration.

Temperature Extremes

The damaging effects of extremely high and low temperatures on electronic equipments, and the ways in which these effects may be lessened or moderated, are becoming well known. Extensive research is being conducted to develop component parts that are better able to withstand operation under extreme temperatures.

The technician must know the effects temperature-caused changes in their physical dimensions have on the electronic parameters of components such as capacitors and slug-tuned inductors. He must also be aware of the mechanical effects of extreme temperatures. Extremely low temperatures cause brittleness in metal and loss of flexibility in rubber, insulation, and similar materials. Extremely high temperatures may cause terminal boards, seals, insulation, and solders to deteriorate and become deformed. Rapid changes of temperature can be especially damaging to electronic component parts.

Humidity

High humidity–the arch-enemy of electronic equipment–is one of the principal causes of electronic component and equipment failure. Technicians should have full knowledge of the effects of humidity on the equipments for which they are responsible. High humidity lowers arc-over levels, causes metals to corrode, and produces physical distortion and rapid deterioration and disintegration on many organic compounds. To make matters worse, high humidity is rarely found without condensation and fungi, with their resultant damaging effects.

Moisture control often involves procedures that may prove injurious to components, or which may be the direct antithesis of solutions to other environment-related problems. This is often the case in tropical areas having both high moisture and high temperature. In such a climate, ventilation of the equipment is required for heat dissipation, but exposure to the atmosphere permits the damaging effects of condensation.

Where electronic equipment is to be used under conditions of extremely high humidity, drain channels and drip holes are sometimes incorporated in the chassis of certain equipments. These openings serve to reduce the overall spread of condensation and reduce electrolytic action. Inspections should include a check of these drains to insure that they are functioning properly.

Woven fabrics and plastic sleeving on delicate or critical components often present a problem of moisture entrapment, with consequent deterioration and failure of the components. Moreover, certain insulations and dielectrics may serve as nutrients for various fungi. Both conditions intensify the need for moisture protection for electronic components.

Under tropical conditions it is sometimes necessary to protect critical component parts from the harmful effects of moisture and temperature variations. Probably the most effective means of doing this is to seal component parts individually. However, sealing equipment or assemblies of component parts does not completely eliminate the problem, because such a seal must, at times, be broken for maintenance or repair. In many cases the technician will not have the means or the inclination to keep the component parts free of moisture to the extent required, especially if the equipment must be stored or remain inoperative while replacement parts are on order.

Corrosive Atmosphere

The effects of corrosive atmospheres on metal parts, insulation, etc., are self-evident and need not be dwelt upon in detail. Acid fumes or electrolyte leakage, although relatively rare in occurrence, can cause serious damage to unprotected electronic equipments. Although the technician should be aware of the damaging effects of all corrosive elements, he must be especially aware of the effects produced by salt spray or salt-impregnated air. The technician must make every effort to protect his equipment from all corrosive atmospheres.

MIL specifications control the corrosion resistance of standard component parts. Nonstandard parts may or may not have the required degree of corrosion resistance; therefore, they must be tested to insure their adequacy in this respect. The use of nonstandard parts should be held to a minimum. Corrosion control will be discussed more thoroughly later in this chapter.

Abrasive Conditions

Sand, dust, and other substances which are abrasive or permeating in nature affect those components which cannot be permanently sealed off from atmospheric conditions, have moving parts, or are readily subject to malfunctions as a result of mechanical interference. Abrasive materials can cause severe wear on commutators and generator brushes and the etching of armatures; excessive friction and binding in gear trains and bearings; interference with contact surfaces of switches and relays, causing arcing or failure to function; pitting of glass and coated surfaces, leaving them open to corrosion; and high-resistance short circuits between points of high potential.

Parametric Pressure Effects

Electronic equipments are sometimes subjected to severe changes in air pressure. Adverse effects on these equipments and components may be prevented by the use of pressurizing chambers, which can serve the additional function of cooling. Adequate pressurization of individual components (to preclude failure from thermal and barometric shock) adds considerably to the weight-size ratio of the equipment. The use of enclosing chambers that will both pressurize and cool increase equipment complexity and results in less reliability. Moreover, overall pressurization sealing complicates maintenance. If one component in a chamber fails, the entire unit must be opened, exposing the other components to the effects of atmospheric conditions. A pressurized equipment that is opened for maintenance is not always resealed immediately; therefore, its component parts must be able to resist ground environmental conditions.

ELECTRICAL NOISE INTERFERENCE AND CONTROL

The electrical noise interference as described in this chapter is defined as any electrical disturbance which causes an undesirable response or malfunctioning in electronic components or systems, including RF interference. Noise interference enters electronic equipments in many ways. Superheterodyne receivers are particularly susceptible to RF interference because of their high sensitivities and nonlinear effects. The undesired radiations do not always enter through the receiving systems antenna, although this path is common. Inadequate shielding of antenna lead-in, transmission lines, and receiver front end, and leaky connectors in transmission lines also provide paths of entry. If the equipment housing does not provide adequate isolation, undesired radiation can enter the receiver's intermediate, video, and audio-frequency circuits. Conductive type interference can also enter the equipment through its power lines. RF interference has grown from a comparatively small problem in the past to become a dangerous threat to present and future ability to communicate efficiently. The trial and error approach to suppression of interference must be complemented or replaced by a scientific approach in both the design and operational phases.

NATURAL INTERFERENCES

Types of interference caused by natural phenomena are those such as electrical storms, rain particles, and interstellar radiation. This type of interference has a greater effect on radio communication than on radar operation.

INHERENT INTERFERENCE

Interference is inherent in the design of receiving equipments. This factor, brought about by the random motion of free electrons in a conductor, causes small potential difference to be developed across the terminals of the conductor. This action, called thermal agitation, is a common source of background noise. Inherent interference is of great concern in radar operation.

Vacuum tubes act as a source of noise because of the nature of their operation. They cause a noise commonly called "shot" effect. Shot effect is created by electrons being emitted from the cathode in a random way so that any current resulting from such emission has a random variation.

Components that transfer energy in the form of heat are interference generators. However, interference of this nature is unavoidable. Proper selection of components will reduce this interference to accepted standards.

MANMADE INTERFERENCE

Interference from manmade sources, such as other electrical or electronic components, is the major source of concern. This type of interference may fall in one or both of two classes, conducted or radiated, according to the mode of transmission.

Radiation interference is any undesirable RF signal which reaches a receiver by direct radiation and degrades its performance. This may be caused by poorly shielded radar modulators, RF energy escaping from waveguide flange couplings, commutators, relays, or cochannel or adjacent channel transmitter outputs.

Conducted interference is any undesired signal which reaches a receiver by direct, inductive, or capacitive coupling through the antenna lead-in cable, power leads, signal leads, or control circuits.

Interference is also classified according to spectrum distribution, namely narrowband and broadband. Narrowband interference consists of either a single frequency or a narrowband of frequencies, generally produced by spurious radiation, parasitic, or harmonic oscillations. Broadband interference is interference that occurs over a wide range of frequencies and is generally a result of an arcing condition.

EFFECTS OF INTERFERENCE ON RADAR RECEIVER

The radar receiver uses only a small portion of the energy radiated by the radar transmitter. The returning echo signal is weak, often being less than 1 microvolt; therefore, the signal must be amplified to a usable magnitude. However, noise is generated in circuits of a receiver because of the small voltage variation set up by electron transit. As the signal voltage is amplified in passing through stages of the receiver, noise is also amplified. When the noise amplitude is greater than the signal, targets may become obscured.

In a radar system, the desired output is a visual pattern displayed on an indicator scope. The interference shows up as a superfluous or distorted visual presentation. The appearance varies with the type of visual presentation.

Noise caused by RF interferance is random in character and can usually be differentiated from a target by its flicker. The flicker is caused by the alternating presence and absence of the RF interference on progressive sweeps.

Some radar receivers are susceptible to interference due to poor RF selectivity and the IF bandpass characteristics which are necessarily wide for proper reception of pulsed signals.

An often-encountered type of interference to a radar system is the interference that is generated by another radar system operating near the same frequency of the affected radar. This will appear on the affected radar indicator. The effectiveness of a radar is reduced if visual displays are obscured by this type of interference. Information pertinent to interference identification can be obtained from a close examination of the radar indicator. Radars employing intensity modulation may be used to indicate two or three dimensions. Pulse type interference is usually observed as a pattern of dots varying in number and intensity. The number of, and relative movement of, these dots are indications of pulse recurrence frequency of an interfering signal relative to the sweep rate of the indicator. An indicator may show a single band of dots similar to a range mark if the PRF of the interfering signal is equal to the sweep rate or multiples of the sweep rate. The position of the interference ring on the plan-position indicator will be determined by the time of arrival of the interference pulse in relation to the starting time of each trace on the indicator.

When the PRF of an interfering signal and sweep rate of an indicator are different and not related by a multiple, the interference becomes apparent as spirals or disarranged dots. Thus, the interference does not appear at the same point, relative to the start of each indicator sweep line. Continuous wave type interference is characterized by its appearance as a solid sector or area of high intensity. A detailed examination of arrangement of the interference pattern structure on a radar indicator is helpful in determining the number of interference signals present. Since it is rare that any two pulse recurrence frequency rates are identical, each interference signal will show a different pattern. Interfering signals are quite often of different amplitude and may cause a corresponding difference on the radar indicator. Careful observation and adjustment of receiver gain controls may prove helpful in distinguishing the number of interference signals when more than one are present.

SOURCES OF INTERFERENCE IN RADAR SYSTEMS

Primary sources of interference in radar equipments are the modulator, transmitter, and electromechanical devices. Thyratrons, which are common in modulator switching application, radiate large quantities of electromagnetic energy while in operation. These radiations will cause interference if proper shielding is not practiced.

The radar modulator can be a source of conducted interference through powerlines. The interference will give an audible effect in receivers and audio amplifiers at the pulse repetition rate of the interfering radar. Shielding and proper bonding of powerlines within the modulator will reduce this type of interference.

The pulse repetition frequency of an interfering radar signal will appear in the output of any receiver if this signal reaches the second detector. It is possible that this signal will be received directly at the second detector if the receiver is not shielded and near a high intensity field.

Electromechanical Devices

Electromechanical devices such as synchros, blower motors, drive motors, vibrators (choppers), and relays are common devices found in practically all electronic equipment, and are all potential sources of noise interference.

MOTORS.–The types of interference generated by d-c motors are:

1. Switching transients as the brush moves from one commutator bar to another. This is usually called commutation interference.
2. Randon transients caused by varying contact between brush and commutator. This is usually called sliding contact interference.
3. Audiofrequency hum (commutator ripple).
4. Radiofrequency and static charges built up on the shaft and rotor assembly.

Direct-current motors used in aircraft systems are of three general types: series wound, shunt wound, and permanent magnet field. The field windings of both series-and shunt-wound motors afford some "padding" or filter action against transient voltages generated by the brushes. The permanent-magnet motor's lack of such inherent filtering makes it a very common source of interference.

It must be emphasized that the size of a d-c motor has little effect upon its interference generating characteristics. The smallest motor aboard may well be the worst offender.

GENERATORS.–The output of an ideal a-c generator is a pure sine wave. A pure sine wave voltage is incapable of producing interference except at its basic frequency. However, the ideal waveform is difficult to produce, especially in small machines.

Practically all types of a-c power generators currently used in naval aircraft are brushless type generators, with less than 5 percent harmonic content in the worst application. Very little interference is generated at the power source.

It should be noted also that a-c motors that do not use brushes are almost never sources of interference.

SWITCHING DEVICES.–Abrupt changes in electric circuits occur when switching takes place. Such changes are accompanied by transients capable of interfering with the operation of radio and electronic systems. The simple manual switch is of little consequence as a source of interference because its frequency of operation is usually not great. Examples of frequently operated switching devices capable of appreciable or serious interference are relays and vibrators.

Since relays are used almost exclusively to control large amounts of power with relatively small amounts of power, they are always potential interference sources. This is especially true when they are used to control inductive circuits. Relay actuating circuits should not be overlooked as interference sources, because even though the actuating currents are small, the inductances of the actuating coils are usually quite high. It is not unusual for the control circuit of a relay to produce more interference than the circuit which it controls.

Induction vibrators are essentially double-pole, double-throw relays which operate at a constant rate. As in any induction type switch or relay, there are two sources of switching transients: the inductive field contacts and the switching contacts. The output waveform of the vibrator is essentially rectangular at some audiofrequency. Its harmonic content is high and filtering is difficult. Vibrators are used as d-c choppers in computer servosystems. They are also found in several radar circuits such as chopper amplifiers utilized in some range circuits. Noise in such circuits as these can be extremely serious.

Suppression Methods

Suppression of noise interference has advanced to the point where the proper application of available techniques will insure that receiving equipment installed in aircraft will operate at optimum efficiency. Four types of suppression techniques are involved.

Isolation is the easiest and most practical method of suppression, and revolves around the possibility of physically separating the source of noise from the input circuits of the receiving equipments affected. As every man-made RF noise source can be considered a small transmitter, it is obvious that the noise source and the leads carrying noise energy should be kept as far away from receiver antennas or lead-ins as possible.

The value of sufficient separation between sources of RF noise and receiver input circuits is not apt to be overemphasized. The isolation method of noise suppression has the advantages of not requiring any additional material or adding any additional weight.

Bonding is a very important means of interference control. It provides grounding of insulated conducting objects on the exterior of the aircraft. When conducting objects are not grounded, flight through precipitation causes high-voltage charges to build up on those objects. Repeatedly, the voltage gets high enough to spark over to an adjacent ground member or the object discharges to the surrounding air by corona conduction. Either mode of discharge causes considerable interference.

Other important functions of bonding are:

1. To protect the aircraft and personnel from lightning discharges by equalization of potentials which might cause arcs and sparks in the aircraft structure.
2. To provide a homogeneous counterpoise for radio transmission and reception.
3. To provide a short path for bypassing RF noise.

All electronic equipment should be grounded to the aircraft structure. This should be done by using short bond straps or sheets of high conductivity (copper or aluminum) metal where it is impossible to use bond strap. No bond strap should be more than 4 inches in length.

Shielding is one of the most effective methods of suppressing noise. The primary object in shielding is to electrically "bottle up" the noise energy. In practical application, this means that the RF noise energy must be kept flowing along the inner surface of the shield. The use of good shielding is particularly effective in situations where filters cannot be used. A good example of this is where noise energy radiates from an RF noise source and the radiated energy is picked up by the various circuits that eventually connect to the receiver input circuits. It is obvious that it would be impractical to filter a number of leads or units that are influenced by the noise energy; hence, the application of effective shielding at the noise source itself is advisable for it will eliminate the radiated portion of the noise energy by confining it within the shield at its source.

RF interference as radiated or conducted from a source may be of a single frequency or may cover an extended band of frequencies, as previously mentioned. When bonding, shielding, or isolation of the source proves ineffective as a means of reducing this interference, it becomes necessary to employ filters to accomplish the reduction. A filter is defined as a selective network which transmits freely electric waves having frequencies within one or more frequency bands and which attenuates substantially electric waves having other frequencies.

The size of a filter may vary widely, depending on the voltage and current requirements as well as the degree of attenuation desired. Filters are usually incorporated in equipment known to generate RF interference, but these filters are often inadequate, and in many cases it is necessary to add filters external to these equipments. This is especially true if the source or interference is coupling interference to paths of entry to a receiver other than the powerline.

The types of filters used in the reduction of interference vary with the application, but each of the general filter types may be found to be particularly adaptable to some specific situation. Most of the electrical devices connected to powerlines have features required for their operation, which are conducive to the generation of interference.

The interference generated by these devices, unless properly attenuated, is impressed upon the powerlines and conducted to the receivers. It may also be conducted into the receivers by inductive coupling to other wiring associated with the receivers. This interference, unless attenuated by means of filters, is then transmitted along these powerlines, entering the receivers at the powerline input; or this interference may be radiated along the powerlines and enter the receiver by means of the antenna system.

Filters are of four kinds and are defined as follows:

1. The low-pass filter, which introduces negligible attenuation at all frequencies below a certain frequency, called the cutoff frequency, and relatively high attenuation at higher frequencies.
2. The high-pass filter, which introduces negligible attenuation at frequencies above a certain frequency, called the cutoff frequency, and relatively high attenuation at lower frequencies.
3. The bandpass filter, which introduces negligible attenuation at all frequencies within the range between two frequencies, and relatively high attenuation at other frequencies.
4. The band elimination filter, which introduces negligible attenuation at all frequencies outside a certain range, and relatively high attenuation at frequencies inside that range.

For information that covers the theory of operation of these filters, refer to Basic Electronics, NavPers 10087-B.

The normal characteristics of a filter are obtained only when the filter is properly terminated in its characteristic impedance.

A wave trap is a filter or network especially designed to reject certain frequencies, or bands of frequencies. Networks of this type may be installed at the antenna of the transmitter or receiver in order to attenuate frequencies outside of the assigned frequency range of the equipment. All such networks must have low insertion loss, or attenuation, for the pass frequencies. In the design and construction of wave traps, the insertion loss is usually below 2 db.

There are two basic circuit configurations for filter networks, the pi-section and the T-section. Each may be broken down into half sections which have an inverted L-shape and are known as L-section filters. If a number of pi- or T-sections are connected in series to form a filter, the resultant network is called a ladder network. Any of the above circuit configurations may be used for radio interference elimination.

In general, the use of simple capacitor filters is to be preferred over that of the more complicated network filters in cases where this type of filter provides the required degree of radio interference attenuation. In this method, the RF noise energy passes through the capacitor to ground. This short-circuiting effect is due to the fact that the capacitor offers a very low impedance path across the noise source terminals.

A given capacitor is effective in bypassing only a limited range of radio interference frequencies because of its internal inductance and the inductance of the connecting leads. The inductance of the capacitor depends upon its capacity, the material of which it is fabricated, and the length of the connecting leads.

The capacitor leads are the major contributors to the inductance of capacitors. Therefore, small mica capacitors with short leads are more effective as filters at high frequencies than large paper capacitors with normally long leads. Electrolytic capacitors should never be used as filters because of the danger of dielectric breakdown.

The advantage of the capacitor type filter is due to the fact that the current used for operation of the radio noise source does not have to pass through the filter. The only energy passing through the filter is the noise energy. The most important limiting factor in the choice of a capacitor-type filter is the breakdown voltage rating of the capacitor. It must be well above the voltage used to operate the source of noise to be filtered. For example, where a 24-volt source of noise is to be bypassed with a capacitor, the working voltage of the capacitor should be at least 50 volts.

From the discussion in the preceding paragraphs it can be seen that equipment design is the prime factor in elimination and control of noise interference. It is also obvious that the responsibility of the AQ for detecting and maintaining control of interference is not limited to the equipment for which he is directly responsible, since operation of fire control equipment will no doubt also affect other systems. In fact many times radio interference is traced directly to fire control equipment. All maintenance personnel must be on the alert for possible sources of interference and must maintain the equipment in its original design configuration. This is especially important where shielding and bonding are concerned, since bonding and shielding are often disturbed during maintenance procedures. This is especially true during installation of changes in an equipment where rerouting of leads and cables, or the installation of new leads or cables is required.

CORROSION CONTROL

In modern aircraft, the need for corrosion control has become a major concern in the availability and maintenance of our striking forces. This is because corrosion is something that destroys equipment and is active 24 hours a day. It is of the utmost importance that its nature be understood in order to combat corrosion.

Most of the useful metals used today have been refined from natural ores found in the earth's surface. These metals are extracted from the ore and are used in various combinations to form alloys with distinct properties. Some of these properties are light weight, strength, and resistance to extreme temperatures. These refined metals have a tendency to return to their natural state, but proper corrosion control will prevent this action taking place.

With the strength demands being made of metals, corrosion control becomes more important because corrosion weakens the metals, thereby causing structural failure. This type failure will cause aircraft safety to decrease and cost of repairs to increase.

CHEMICAL CORROSION

Most surface corrosion is chemical in nature and is generally caused by salts, acids, or gases coming in contact with the metallic surfaces of the aircraft or equipment.

Aircraft and their associated equipment which are based aboard ship are particularly vulnerable to salt spray and gases which originate on board a ship. Shore-based aircraft are also exposed to contamination, but to a somewhat lesser degree. Although salt spray and gases in the atmosphere cause rapid chemical corrosion, it should be understood that some corrosion will take place under the most ideal situations.

Chemical corrosion is a chemical process which is essentially the reverse of the process of extracting the metals from their ores. For the most part, metals occur naturally as metallic oxides. After refining, regardless of whether or not alloyed, base metals generally possess a tendency to return to their natural state. However, this is not sufficient in itself to initiate and promote this reversion. There must also exist a corrosive environment in which the significant element is oxygen. Corrosion, then, is the process of oxidation.

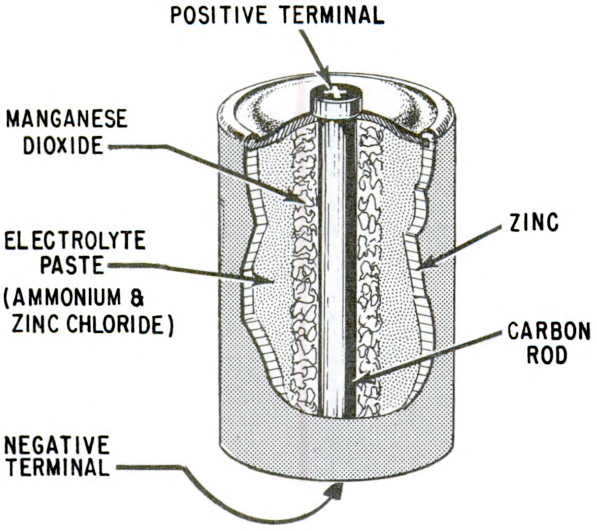
ELECTROCHEMICAL CORROSION

While chemical corrosion is generally readily apparent, electrochemical corrosion is insidious in its destruction. Electrochemical corrosion includes galvanic or dissimilar metals corrosion. This type of corrosion is caused by an exchange of electrons between two metallic areas of different activity (potential) by way of an electrolyte. Three conditions must be present in order for electrochemical corrosion to take place. The first condition is that two or more areas of metal are needed to act as electrodes. The second condition is the requirement of the presence of an electromotive force. The last requirement is the presence of an electrolyte to complete the formation of a cell.

It is not necessary to know all the theories concerning electrochemical corrosion, but a brief understanding of the deterioration of metals will be beneficial in combating this type of corrosion.

An ordinary flashlight cell serves as a good subject to explain electrochemical corrosion. (See fig. 4-2.) The outside container is made of zinc and serves as the anode which is corroded as the cell is operated. The cathode of the chemical cell is the carbon electrode in the center of the cell. The moist ammonium and zinc chloride paste within the zinc container is the electrolyte which electrically connects the carbon electrode with the zinc anode.

If a conductor is connected externally to the electrodes of a cell, electrons will flow under the influence of a difference of potential across the electrodes from the zinc (-) through the external circuit to the carbon (+) returning within the electrolyte to the zinc. As the electrons flow, the zinc coating will oxidize. This oxidation is the same as corrosion. For a more detailed explanation of the operation of a cell, refer to Basic Electricity, NavPers 10086-B.



AT.274

Figure 4-2.–Dry cell, cross sectional view.

Since the only requirements for a cell are cathode, anode, and electrolyte, it should be apparent that the physical size of a cell is dependent only on the physical size of its components. A cell may be formed where a resistor lead is soldered to a terminal, two sheets of metal are joined, or around a rivet head and the adjacent metal. (See fig. 4-3 (A) and (B). A cell may even be formed when an electrolyte is present on one price of metal where two metallic crystals in the same alloy, but of different composition, are in electrical contact with each other (See fig. 4-3 (C).)

While the formation of one minute call may be insignificant, it should be understood that a cell will continue to grow as long as the corrosion action is allowed to continue. This cell expansion may take place in a short period of time and become a significant structural safety factor due to the deterioration of the metal.

It should be apparent that the presence of an electrolyte allows corrosion to take place. The more efficient the electrolyte and the greater the potential difference between anode and cathode, the higher the corrosion rate (growth) will be. It should be noted that the anode and cathode are always present and cannot be removed; therefore, the solution to the problem of corrosion is to remove the electrolyte. When the electrolyte is removed, a cell no longer exists and corrosion is held to the minimum.

Both types of corrosion normally depend on moisture to form an electrolyte. Even moisture in the air is often sufficient to start the corrosion action. All attacks of corrosion start on the surface of the metal where it is exposed to the corrosive environmental; and if allowed to progress, it will work its way into the core of the material. Since corrosion never originates in the core, there is always some form of evidence of corrosion on the surface.

CORROSION PREVENTION

Now that it is understood that the "villain" of corrosion is the electrolyte, the solution to corrosion prevention is to keep any electrolyte from coming into contact with the electrodes. This is accomplished by keeping a protective coating on the metallic surfaces.

Much has been done to improve the corrosion resistance of naval aircraft. This is in the area of improvement in materials, surface treatments, insulation, and protective finishes. All of these have been aimed at reducing maintenance effort as well as improving reliability. In spite of these improvements, corrosion and its control are very real problems that require a continuous preventive maintenance program.

Corrosion preventive maintenance includes the following special functions:

1. An adequate cleaning program.
2. Thorough periodic lubrication.
3. Detailed inspection for corrosion and failure of protective systems.
4. Prompt treatment of corrosion and touchup of damaged protective coating.

Inspection

Inspection for corrosion is a continuing problem and should be handled on a day-to-day basis. Over-emphasizing a particular corrosion problem when it is discovered, and then forgetting about corrosion until the next crisis, is an unsafe, costly, and troublesome practice.

Most periodic maintenance requirement information has been placed on Maintenance Requirements Cards which are complete enough to cover all equipments in the aircraft. No equipment of the aircraft should go unchecked. Through experience, it will be learned that most equipments have trouble areas where corrosion will occur. Equipments in helicopters are particularly susceptible to corrosion due to the tactics in which the helicopters participate.

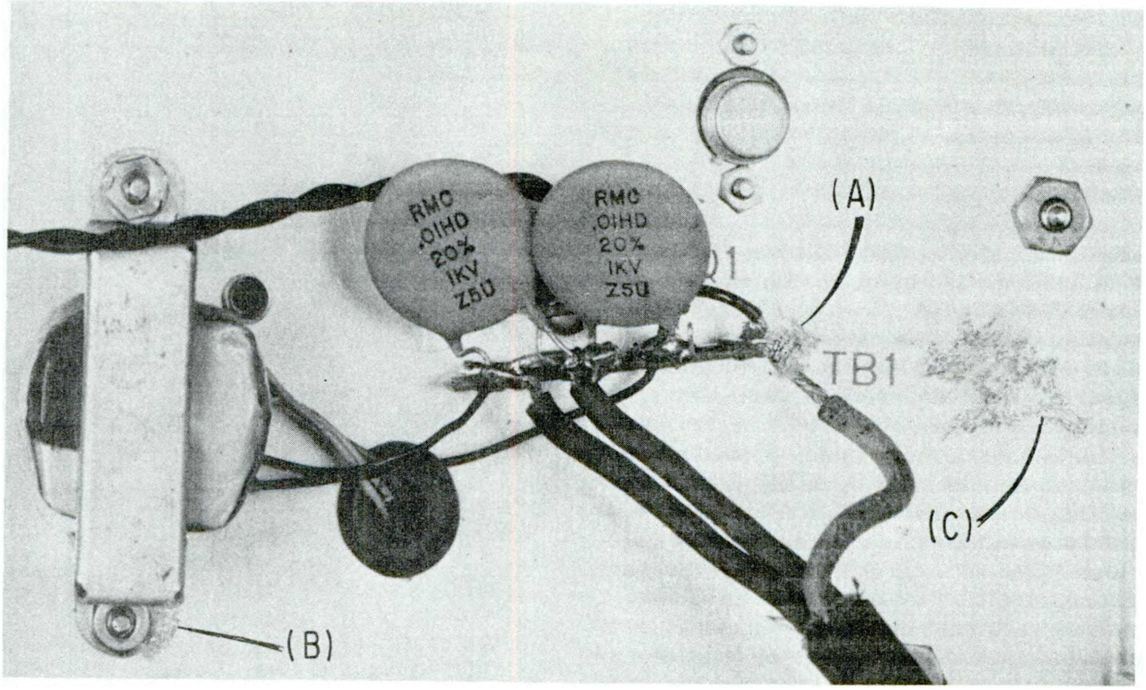


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Figure 4-3. –Electrochemical corrosion.

Protective Measures

An effective protection from corrosion requires the earliest possible repair of damaged protective coatings, including the removal of corrosion products and the restoration of corroded surfaces. This involves the maximum use of supplementary protective agents during any waiting periods or until such time as more positive protection can be restored. It must be a continuous program and recognized as a specific responsibility.

Periods of neglect or touchup maintenance, which may be necessary under operating conditions, should be followed by a period of concentrated effort to correct any deficiencies which have started. A successful preventive maintenance program will tend to reduce the effects of severe service environments and the susceptibility of most aircraft and equipment to damage by these environments.

ANTICORROSION MATERIALS.–During manufacture, electronic equipments are usually sprayed with a protective coating that seals out moisture, thus preventing corrosion and fungus growth. In repair of these equipments, it is sometimes necessary to remove the protective coating by scraping or by the use of a solvent cleaner.

After making circuit repairs, the protective coating should be replaced. Rosin fluxes form coatings on solder connections that prevent oxidation during and after the soldering process, thus providing one form of replacement. A good general rule is that materials used should be those covered and controlled by military specifications, preferably those authorized specifically for use on aircraft. Use nonspecification materials only in emergencies, or where specific instructions so direct.

FUNGUS-RESISTANT MATERIALS.–Fungus susceptibility of materials has long been a serious problem, particularly with electronic equipments which may be subjected to extremes of humidity under tropical temperatures. While the fungus itself is objectionable since it generally "fouls" all types of equipment, its most serious effect is the increased possibility of shorting and arcing because of its moisture content.

The fungus problem has been further aggravated in the past decade by the increased use of a large number of organic materials in equipment used by the Navy. These materials vary in nature and size from large sheets of reinforced plastic for structural components to special dielectric substances used in complex electronic gear.

Fungus removal generally follows the same procedures of corrosion removal.

CORROSION REMOVAL

In corrosion control, time is of the essence. Until the electrolyte is removed, the chemical reaction will continue. Although most of the electrolyte is removed, some will remain in inaccessible locations of the chassis or modules making the cleaning process particularly difficult.

When this occurs, the proper procedures and cleaning materials must be used. The remainder of this discussion will be devoted to the techniques and materials used in correcting this problem.

The extent of cleaning, using the following techniques, requires the decision of the Corrosion Control Officer assigned to the organization.

Dry Cleaning

When corrosion or salt crystals are discovered in a piece of equipment, as much of this as possible should be removed by dry methods. This entails breaking the solids from the metallic parts by wiping with a dry cloth or brushing with a stiff bristle brush. Care should be taken not to damage any of the components of the equipment.

Any remaining loose residue should be removed by the use of low pressure dry air.

Although it may appear that all of the contamination has been removed, this generally is not the case. At this point a decision must be made as to the possibility of contamination existing in the inaccessible or undetectable areas of the equipment. If this decision indicates that contamination still remains in the equipment, then further steps must be taken in the form of liquid cleaning.

Fresh Water

Although immersion or flushing of electronic and other equipment in or with water violates previous training, fresh water is one of the agents used to remove salt water and deposits from equipments. After the equipment has been subjected to fresh water, the water must then be removed. This may be accomplished by dry air pressure, by the use of spray (water displacement) fluid, or by a drying oven.

DRY AIR PRESSURE.—If compressed air is not available, any type of compressor that will deliver clean dry air at 80 psi will be adequate to furnish air for spray cleaning and for blowing as much water as possible from the wet equipment before using the water-displacing fluid.

WATER-DISPLACING FLUID.—This fluid is generally available in pressurized aerosol cans or in drums and is called a spray-dry water-displacement composition. A paint spray gun or other spraying equipment for applying bulk water-displacing composition in a fine mist may be used if an aerosol-pressurized water-displacing composition is not available.

The equipment is sprayed with this composition, and then some means of drying such as heat oven, air pressure, or natural evaporation should be employed.

DRYING.—Forced draft ovens with accurate temperature control large enough to accommodate the equipment being cleaned are preferable for final drying of the cleaned equipment. If ovens are not available, a small room equipped with an exhaust fan and heaters can be used. The temperature in the drying facilities should be between 120° and 160° F, depending upon the temperature sensitivity of the equipment being dried. If a heated room is used for drying, its temperature should be at least 30° F above the ambient temperature.

Detergent

In some cases a detergent must be used. The detergent is available in aerosol type containers or in bulk form. Detergent is used because salt crystals have formed on the equipment or an oily deposit is present in the equipment. The detergent will dissolve the salt crystals and will also emulsify and suspend oil deposits in the solution. In either case, fresh water must be used to rinse the contamination solution from the equipment.

Ultrasonic Tanks

An ultrasonic tank is a container for fresh water or a cleaning agent. The solution is vibrated either by a transducer or by forced air. The agitation helps remove particles from inaccessible areas of the electronic equipments. The frequency of the transducer is in the ultrasonic range (above 15 kilohertz) and accomplishes the cleaning in a much shorter period of time than the forced air. When equipment has been removed from an ultrasonic tank, the previously mentioned procedures for drying should be completed.

SALVAGE PROCEDURES

The following steps comprise the routine procedure for salvaging sea water contaminated electronic equipment:

1. Immediately after remove of the equipment from sea water contamination, the equipment should be flushed thoroughly with fresh water.

2. The equipment should be disassembled to units of a size that permits immersion in an ultrasonic bath and to allow better access of cleaning solutions.
3. Remove contamination with emulsion cleaning composition in the ultrasonic tank.
4. Rinse in an ultrasonic tank of fresh water or rinse with a fresh water spray.
5. Blow the rinse water from the equipment with clean compressed air and follow with an application of water-displacing composition.
6. Dry in an oven or by natural evaporation.
7. Check for damage, repair and lubricate as required, then return to service.

Equipment which cannot be dismantled or is too large for cleaning in the ultrasonic tank can often be cleaned by spraying with a cleaning emulsion. Upon completion of the emulsion application, the equipment should be rinsed and dried as previously indicated.

CHAPTER 5

RADAR SYNCHRONIZERS

The circuits in an aviation fire control radar system that control or synchronize the operation of the various components of the system are known as timing circuits.

The functions which the timing circuits must perform depend to a large extent upon the purpose of the set, the type of modulator used, and the method of data presentation employed. Thus, the functional block diagram shown in figure 5-1 (A) does not apply to any particular set, but shows a method of control (timing) which is used in aviation fire control radar sets.

Figure 5-1 (B) shows the control pulses furnished by the timer and their proper time relationships to the transmitted pulse.

The first pulse (waveform (1), fig. 5-1 (B)), is the modulator trigger. It causes a pulse of RF energy to be transmitted as shown in waveform (2). The modulator trigger also acts as a reference point from which the other operations are timed.

The timer also supplies a trigger pulse to start the range sweep as shown in waveform (3). It should be noted that the sweep trigger precedes the modulator trigger pulse. This provides sufficient time for the sweep generator to overcome its nonlinear characteristics which will be discussed later. However, in some aviation fire control radar sets both the modulator trigger and the range sweep trigger are delayed. The modulator trigger delay is a fixed amount, and the range sweep delay may be varied to allow the start of the range sweep as desired. This enables the range sweep trigger to start the sweep at exactly the same time as the transmitter fires, regardless of any inherent delay in the sweep circuit. This time is usually referred to as time zero (t_0), shown as the dotted line in figure 5-1 (B).

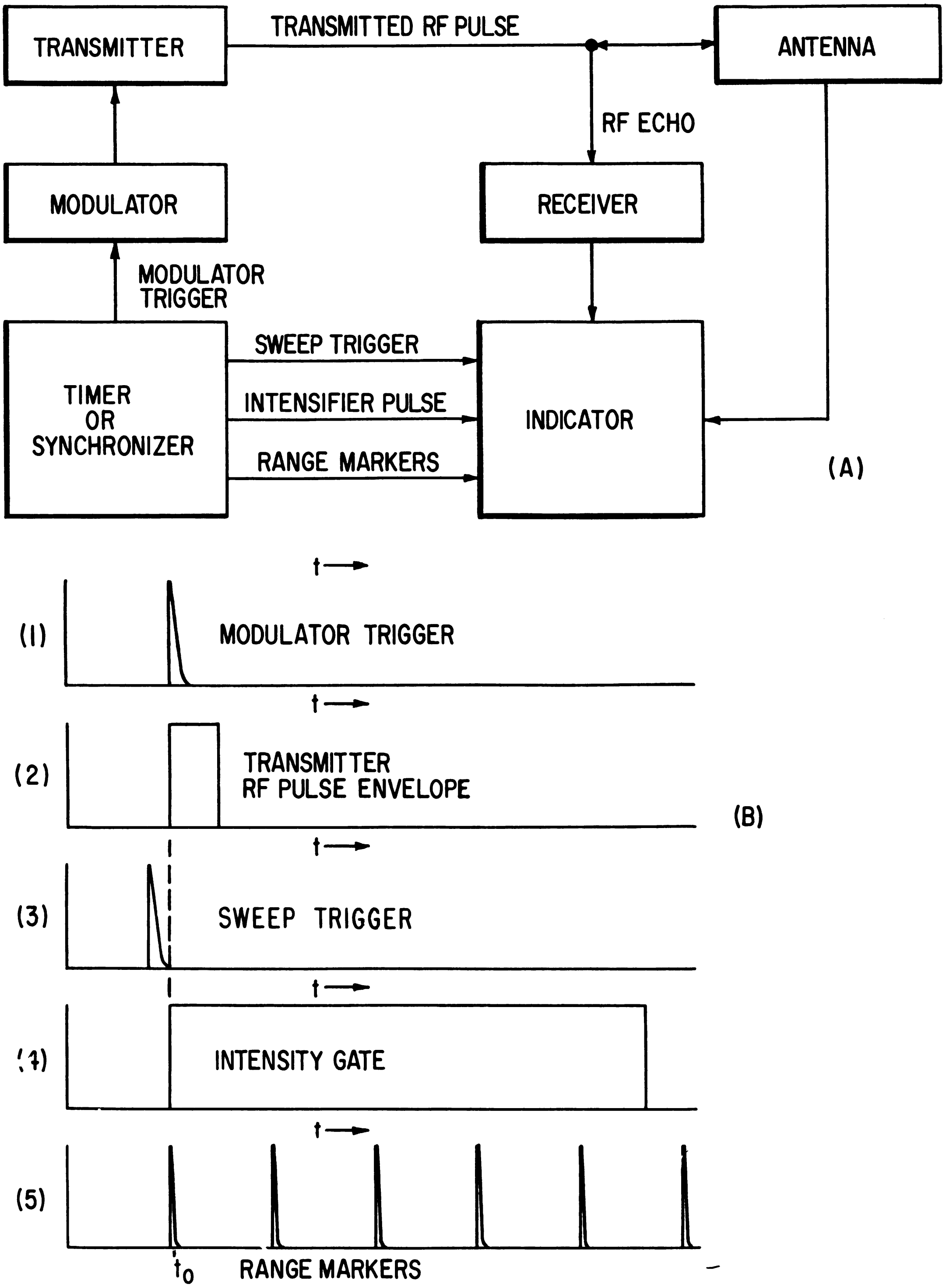
Another voltage which the timer may supply is an intensifier pulse, waveform (4), usually referred to as an intensity gate. The intensity gate functions to blank the indicator except during the time of the desired range sweep. Thus, signals arriving outside the time interval corresponding to the desired range are eliminated. The intensity gate shown in waveform (4) is applied to the grid of the CRT. This gate cancels the CRT's disabling voltage, thus allowing the video signal to intensity-modulate the electron stream. An alternate method is to make the CRT normally operative and to apply a negative gate, or blanking pulse, to blank the screen when signals are not to be received.

An important function of any radar set is the determination of range of the targets observed. The methods of range determination vary. Some use a simple transparent overlay (upon which ranges are marked) for the indicator screen. Others have complex circuits used for very accurate range measurements in aviation fire control systems. One method for fire control sets is the use of range markers generated in the timer. The markers are pulses of very short duration, as shown in waveform (5) of figure 5-1 (B). These pulses, separated by specific intervals of time, are applied to the indicator in the same manner as video signals. They appear as straight lines on a B-type indicator or circles on a PPI-type indicator. (NOTE: Indicators are discussed in chapter 8 of this manual.)

All the control pulses described and illustrated in figure 5-1 (B) are repetitive; that is, they appear once during each cycle of operation. The timer furnished several series of pulses, each having the proper waveform and time relationship to the others. In order that a timer may provide these control pulses, it must contain the following elements:

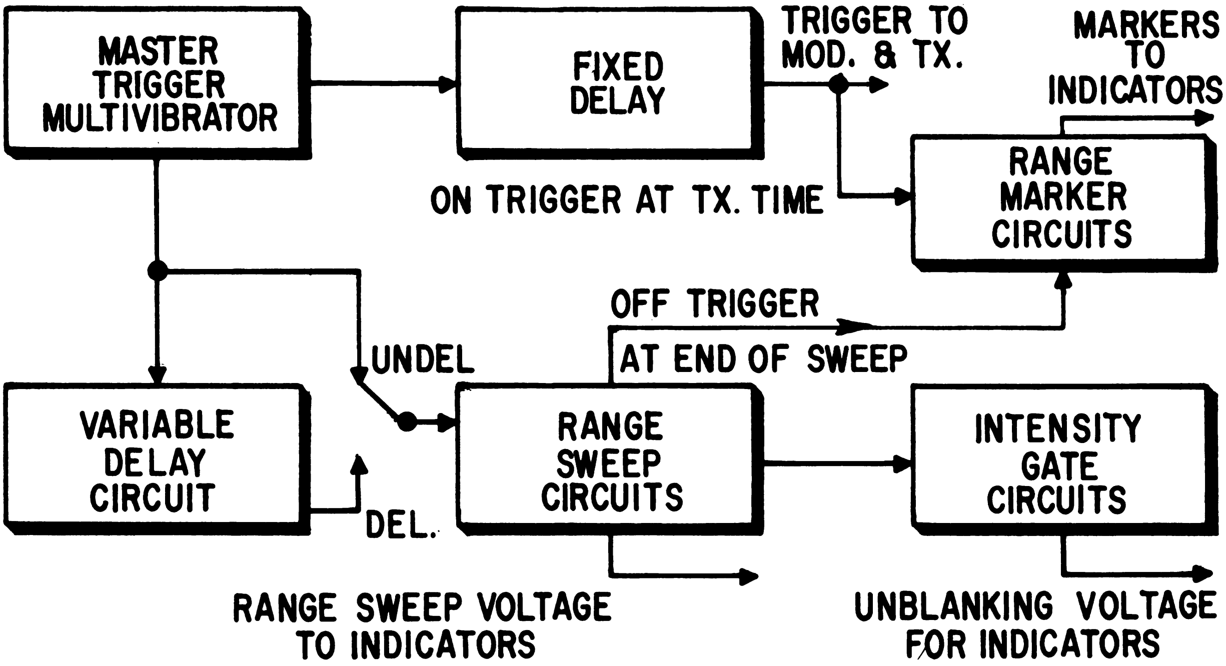
1. A master oscillator to determine the pulse repetition frequency (PRF). This is usually a multivibrator.
2. A means of forming pulses of the desired shapes and time relations (usually multivibrators, blocking oscillators, and delay circuits).
3. Circuits capable of matching the waveform generator to either its output circuit or to a transmission line without distortion of the waveform (the cathode follower).

All of the previously mentioned circuits have been discussed in detail in the Rate Training Manual, Basic Electronics, NavPers 10087-B.



AQ. 5

Figure 5-1.–(A) Block diagram showing functions performed by a typical AFC radar timer; (B) synchrogram of control pulses furnished by the timer shown in figure 5-1(A).



AQ. 6

Figure 5-2. –Simplified block diagram of a synchronizer using a multivibrator master timer.

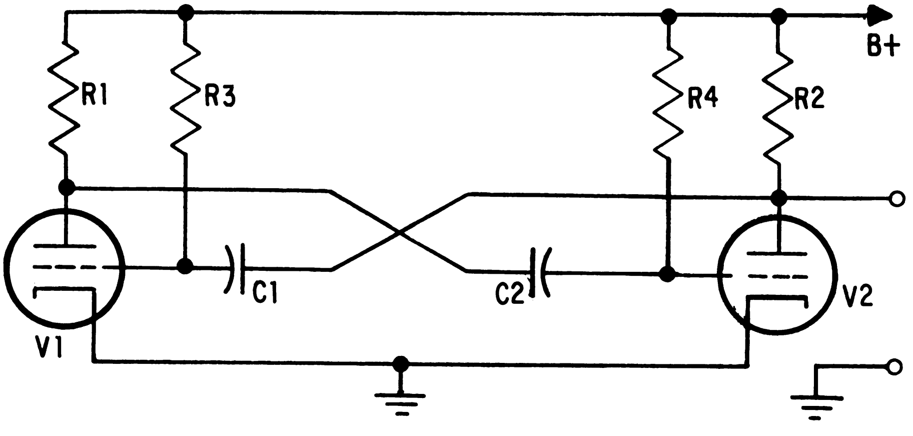
The remainder of this chapter will consider in detail those circuits which are found most frequently in the various aviation fire control radar synchronizers and not discussed thus far.

MULTIVIBRATOR TIMER

The multivibrator type master oscillator is used in most aviation fire control radar systems, and is usually referred to as the heart of the radar. The multivibrator timer may do the following:

1. Establishes the pulse recurrence frequency.
2. Triggers the range marker generating circuits.
3. Triggers the sweep circuits.
4. Triggers the transmitter.
5. Establishes a time base for the intensity gate.

Figure 5-2 is a simplified block diagram of a synchronizer utilizing a multivibrator as the master timer.



AQ. 7

Figure 5-3. –Free-running multivibrator.

The master trigger multivibrator is free running. Its output frequency, which is determined by the time constants of the RC networks in the grid circuits determines the PRF of the set. Figure 5-3 is an illustration of a free-running multivibrator. C1R3 and C2R4 make up the RC networks in the grid circuits.

The output taken from the plate circuit is fed to the fixed delay circuit for firing the transmitter and the variable delay, or directly to the range sweep circuits if no sweep delay is to be employed. (Refer to fig. 5-2.) The fixed delay circuit delays the firing of the transmitter until the nonlinear portion of the range sweep is past. The output of the fixed delay is then fed to the modulator and range marker circuits simultaneously. Thus, the range marker circuits are turned on at the time the transmitter fires, and turned off at the end of the range sweep time by a pulse from the range sweep circuits. The output of the range marker circuits is fed to the indicator in the form of evenly spaced pulses and appear as intensified range lines on the scope.

The trigger to the range sweep circuits may be either delayed or direct. If direct, the range sweep will start immediately; if delayed, the range sweep will start sometime after the transmitter is fired, delay time being equal to the output of the variable delay circuit.

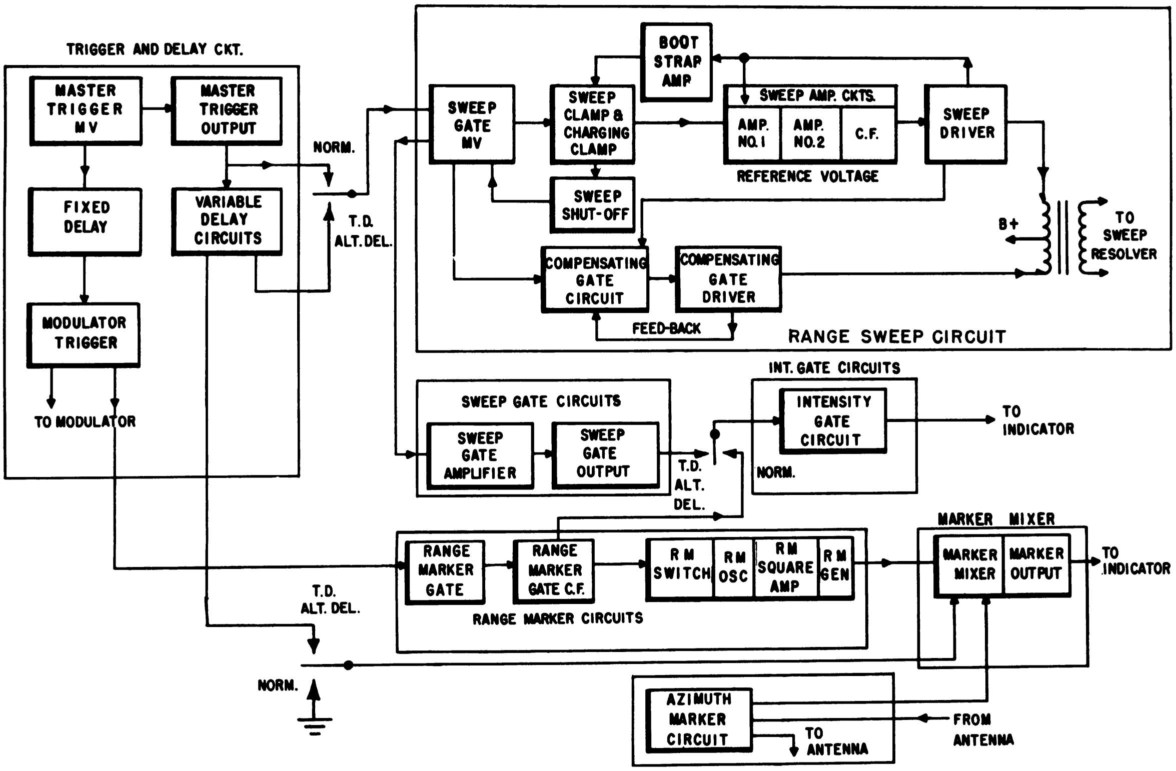
The range sweep circuits provide the indicator with sweeps of various time duration (ranges). They also furnish trigger pulses to start and stop operation of the intensity gate circuit (for unblanking the indicator during sweep time only), and an output to the range marker circuits to turn the marker circuits off at the end of sweep time.

FUNCTIONAL OPERATION OF SYNCHRONIZER

Now that you have a general idea of the basic requirements of a radar synchronizer, its operation will be discussed in more detail.

Figure 5-4 is an illustration in block form of a typical radar synchronizer similar to the type used in the AN/ASB-1 bomb director system.

For ease of explanation, the synchronizer circuits have been grouped into the following types:



AQ. 8

Figure 5-4. –Synchronizer block diagram.

1. Trigger and delay.
2. Range sweep.
3. Sweep gate.
4. Intensity gate.
5. Range marker.
6. Azimuth marker.
7. Marker mixer.

The circuits in each block and their input and output waveforms are discussed in the folowing paragraphs.

TRIGGER AND DELAY CIRCUITS

Master Trigger Multivibrator

This circuit produces the timing pulses from which the timing of the complete radar is controlled. Its output determines the repetition frequency of the radar set. Typical PRF's used in fire control are:

1. 800 pps on short range.
2. 400 pps on beacon operation.
3. 200 pps on long range.

The output of the master trigger multivibrator is fed to the fixed delay circuit and to the master trigger output circuit.

Fixed Delay and Modulator Trigger Circuits

The function of the fixed delay circuit is to delay the modulator trigger pulse for 8 μsec. This delay is sufficient to allow use of the most linear portion of the output from the range sweep generator. The modulator trigger circuit generates the modulator trigger pulse when triggered by the output of the fixed delay circuit. It also provides the necessary impedance match between the fixed delay circuit and the cable used to transmit the trigger pulse to the modulator. A timing pulse for starting the range marker circuits is also provided.

Master Trigger Output

The master trigger output circuit differentiates the square wave supplied by the master trigger multivibrator and forms a negative output pulse at the desired PRF. This negative pulse is called the master timing pulse (trigger). It provides the trigger (without delay) for starting the range sweep generator circuits on normal operations. It also supplies the variable delay circuit with a starting trigger when the equipment is using altitude delay (ALT. DEL.) or time delay (T.D.).

Variable Delay Circuit

This circuit delays the sweep generator trigger received from the master trigger output circuit. The delay, which is determined by the mode of operation being employed, is generated by a phantastron circuit which is discussed later in this chapter.

RANGE SWEEP CIRCUITS

The purpose of the range sweep circuit is to produce a linear time base for determining target range. Referring to figure 5-4, it should be noted that the only input to the circuit is applied to the sweep gate multivibrator. This multivibrator is triggered by a negative pulse supplied by the master trigger output stage on normal operation, or by the variable delay circuit on altitude delay and time delay operation. The multivibrator produces a positive square wave gating voltage which is applied to the sweep clamp circuit which controls the generation of the sawtooth. It also produces a negative square wave voltage which provides a compensating gate trigger pulse at the end of the range sweep time.

The output sawtooth is amplified and fed to the sweep drivers where it is further amplified. It should be noted that an output from the sweep driver is fed back to the first sweep amplifier and through a bootstrap amplifier to the sweep clamp and charging clamp. The feedback loop helps to improve the linearity of the sweep. This is explained under "Circuit Analysis."

The output of the sweep driver is fed to a transformer where it is combined with the output from the compensating gate driver. The composite waveform is fed to the sweep resolver located on the antenna.

The compensating gate circuits are employed to produce the necessary waveform to return the range sweep to its correct starting point prior to the start of the next range sweep. It is triggered by an output from the sweep gate multivibrator at the end of range sweep time. The compensating gate driver provides the necessary amplification based on the requirements of the set.

RANGE MARKER CIRCUIT

The primary function of the range marker circuit is to provide range markers to be used in determining range to targets. It also supplies a gating pulse to the intensity gate circuit on normal operation. It consists of a range marker gate, range marker gate cathode follower, range marker swtich, range marker oscillator, range marker squaring amplifier, and the final amplifying and shaping circuit called the range marker generator. The output range marks are fed to a marker mixer.

SWEEP GATE CIRCUIT

The purpose of the sweep gate circuit is to control the operation of the intensity gate circuit when either T.D. or ALT. DEL. is being used. This insures that the intensity gate circuit works in unison with the sweep generator.

INTENSITY GATE CIRCUIT

The purpose of the intensity gate circuit is to produce a rectangular waveform which is applied to the indicator to overcome its blanking bias. The output waveform must be synchronized with the range sweep voltage and be of equal time duration.

AZIMUTH MARKER CIRCUIT

The azimuth marker is a line produced once each scan to provide the operator with the necessary bearing information. The azimuth marker circuit generates the electrical pulses which appear as azimuth markers. However, these pulses are not fed directly to the indicators but are fed through the marker mixer circuit where they are combined with other markers.

MARKER MIXER CIRCUIT

The inputs to the marker mixer circuit are range marks from the range marker circuits and azimuth markers. The function of this circuit is to further amplify these markers before they are fed to the indicators.

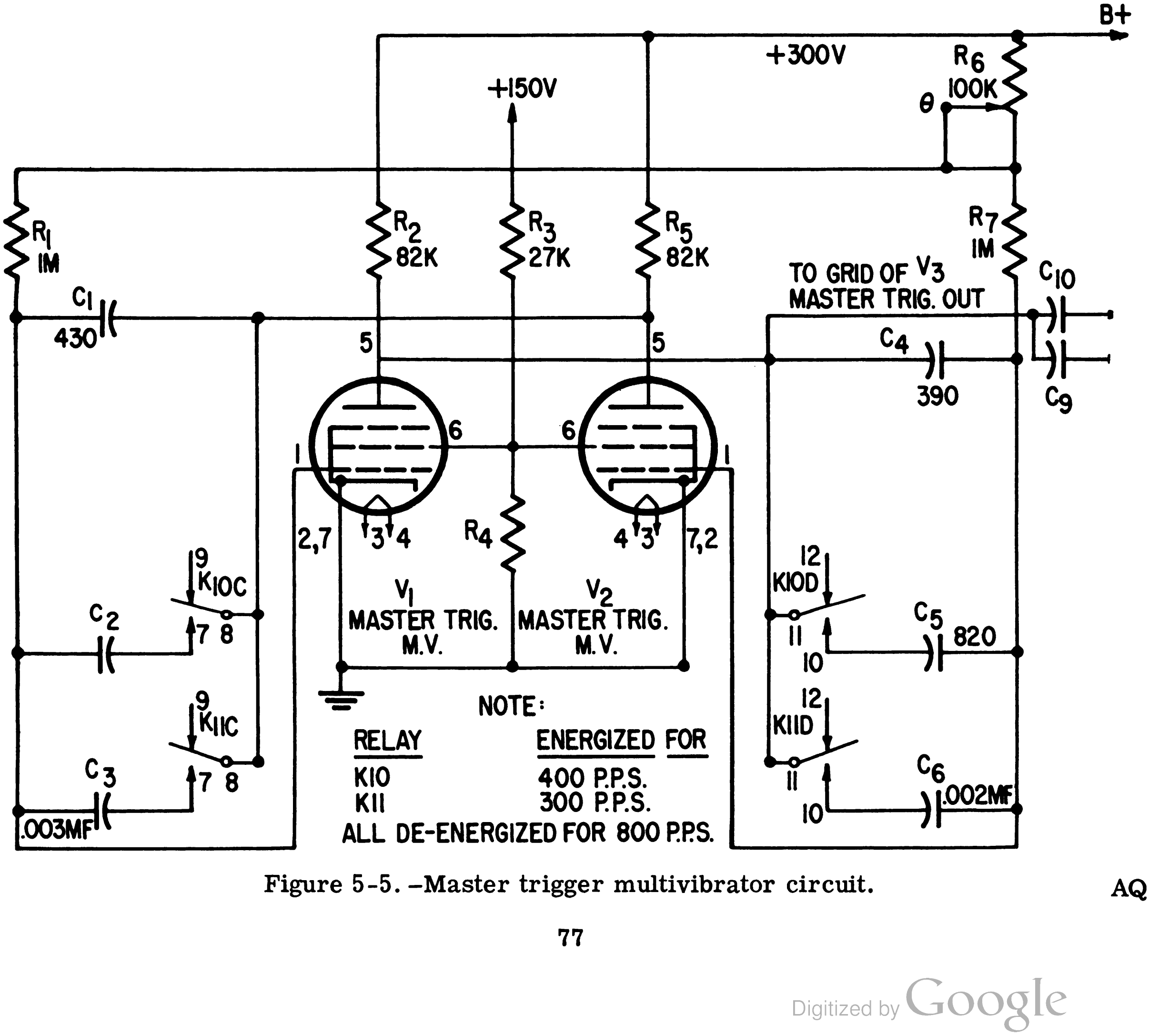


Figure 5-5. –Master trigger multivibrator circuit.

AQ. 9

CIRCUIT ANALYSIS

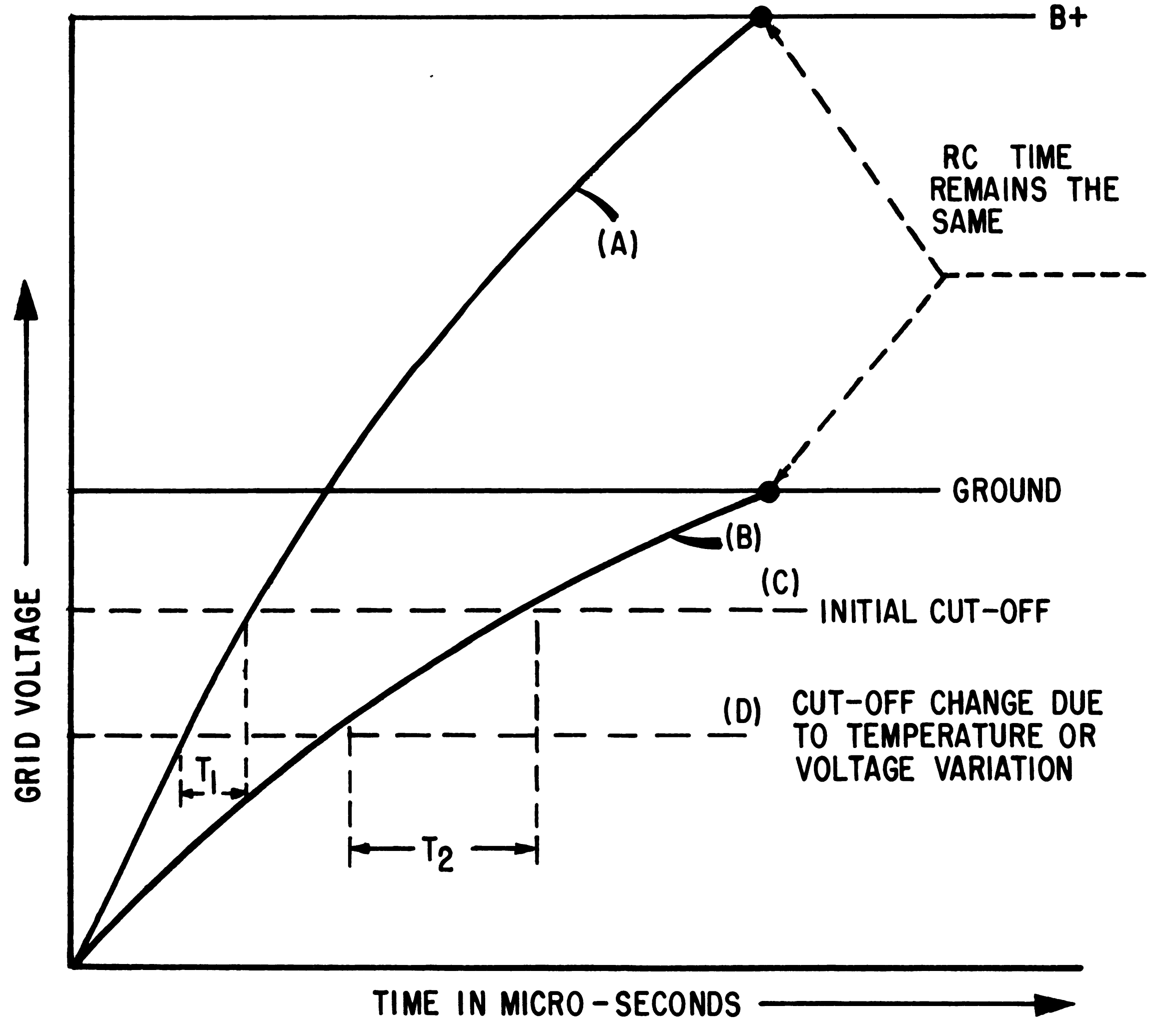
The theory of operation of the circuits represented by the synchronizer block diagram (fig. 5-4) is discussed in this section. However, the discussion of basic circuits, covered in detail in Basic Electronics, NavPers 10087-B, is limited to their application in the operation of the synchronizer.

MASTER TRIGGER MULTIVIBRATOR CIRCUIT

The master trigger multivibrator circuit is a free-running multivibrator. (See fig. 5-5.)

The circuit is basically the same as the free-running multivibrator discussed in chapter 8 of Basic Electronics, NavPers 10087-B. However, the circuit illustrated in figure 5-5 utilizes a somewhat different grid circuit. It should be noted that relays are used to connect capacitors in parallel with the grid capacitor in each grid circuit. This permits the output frequency to be changed by energizing the various relays as the equipment's mode of operation is changed.

Another variation from the basic circuit is the manner in which the grids are connected. In the discussion of the basic circuit in Basic Electronics, the grid resistors are connected to ground. However, by connecting the grid



AQ. 10

Figure 5-6. –Time versus grid voltage.

resistors to the B-plus supply, the stability of the oscillator is increased.

By studying the graph of time versus grid voltage (fig. 5-6), the reason for the increased frequency stability should be apparent. Curve A is the RC discharge curve with the grid resistor connected to B-plus. Curve B is the discharge curve with the grid resistor returned to ground. It should be noted that the RC times of the two curves are exactly the same, but the curves differ considerably in slope.

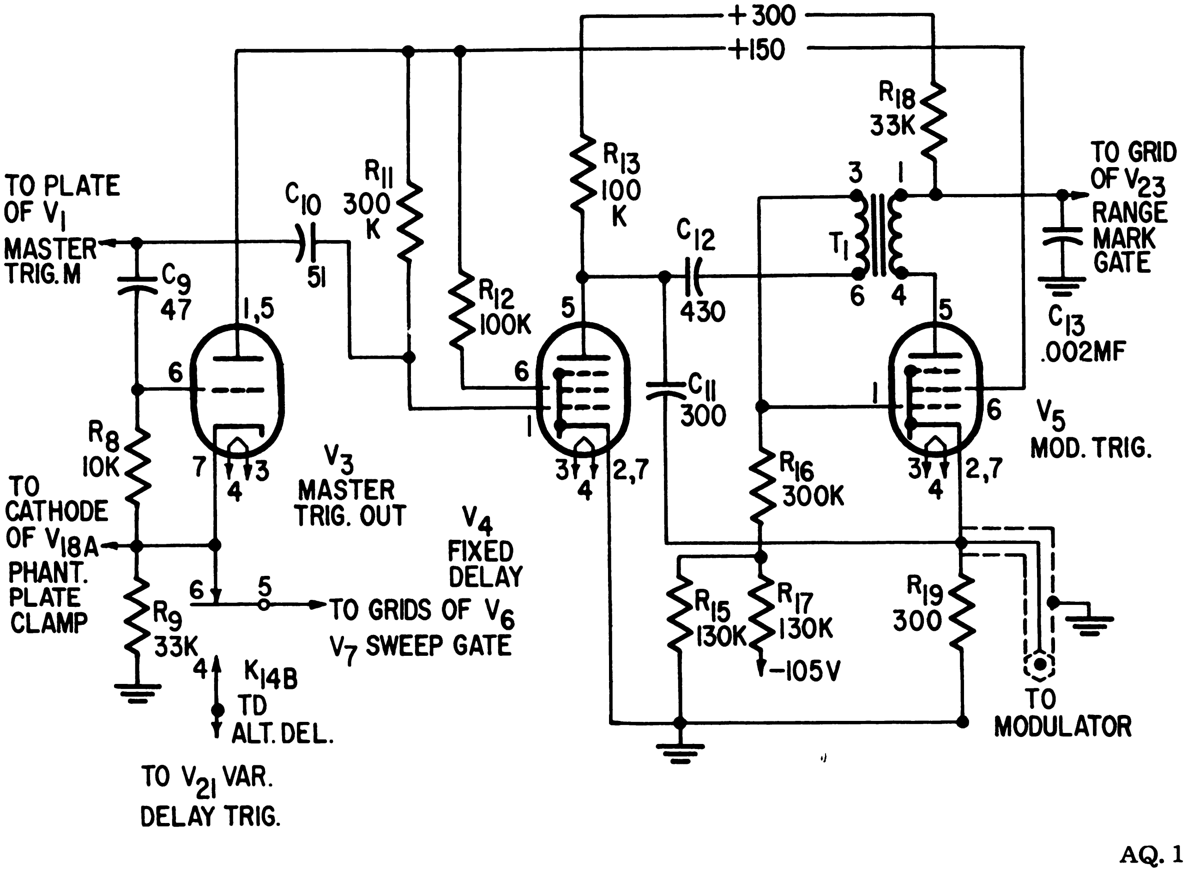
For the purpose of explanation, assume that line C is the cutoff point for the tubes shown in figure 5-5. Note the points at which curves A and B cross line C. Now consider a change in circuit conditions which would move the cutoff of each tube to line D. Such a change could result from a change in temperature within the equipment, from vibration, or from a change in altitude. The difference in time required for each grid to reach cutoff is represented by T_1 and T_2. T_2 is much larger than T_1 which would result in a smaller change in output frequency for the circuit represented by curve A. The changes shown in figure 5-6 are greatly exaggerated for the purpose of illustration.

Resistor R6 (fig. 5-5) is used to make a fine adjustment on the output PRF. The adjustment affects all modes of operation and is performed when alining the synchronizer.

The output of the multivibrator is taken from the plate of V1 and is a positive rectangular waveform at a PRF rate. It is coupled through C10 to the fixed delay circuit V4 to be shaped into a triggering pulse for the transmitter and range marker circuits. The square wave is also coupled through C9 to V3, the master trigger output stage to be shaped into a trigger pulse for the range sweep circuit.

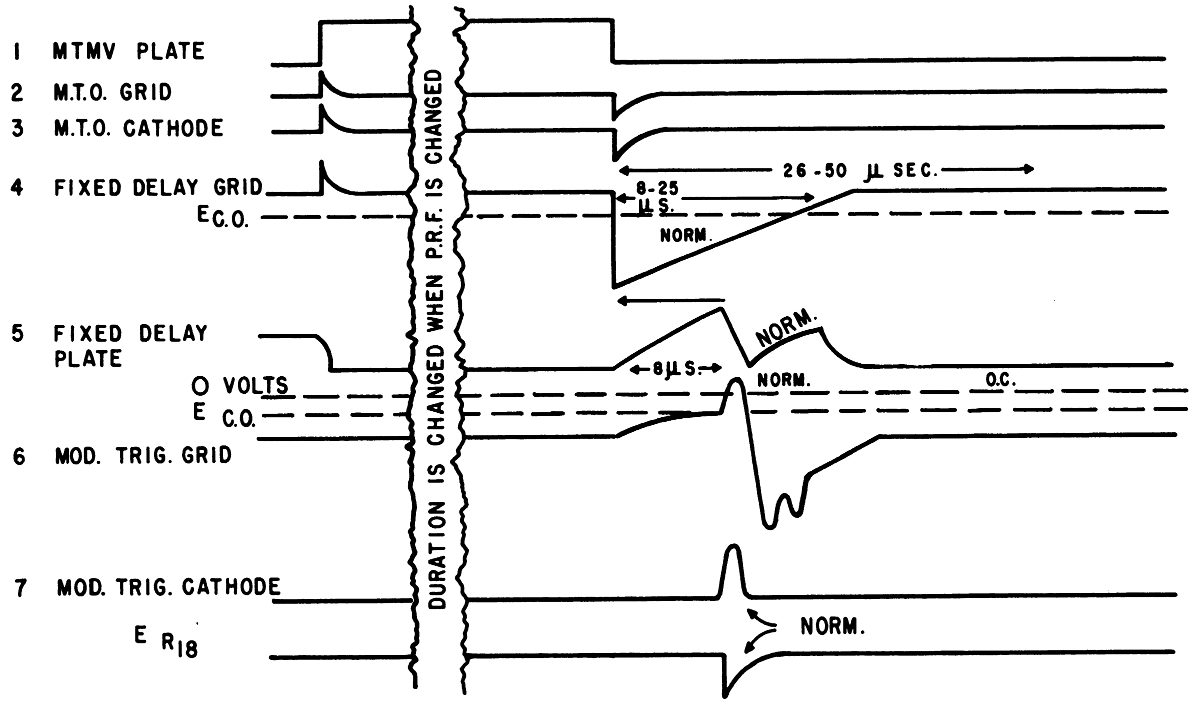
MASTER TRIGGER, FIXED DELAY, AND MODULATOR TRIGGER

For the discussion on the master trigger output, fixed delay, and modulator trigger circuits, refer to figures 5-7 and 5-8.



AQ. 11

Figure 5-7.–Master trigger output, fixed delay, and modulator trigger circuits.



AQ. 12

Figure 5-8. –Waveforms of master trigger multivibrator, master trigger output, fixed delay and modulator trigger circuits.

Master Trigger Output

The master trigger output stage consists of a typical cathode follower with an RC network in its grid circuit. This network, consisting of C9, R8, and R9, presents a short RC time constant to the input positive square wave from the master trigger multivibrator. The square wave (waveform (1), fig. 5-8) is differentiated as shown by waveform (2).

By studying the circuit, it should be obvious that the positive spike will not affect the conduction of V3 since the grid will draw current and quickly charge C9. However, the negative spike formed by differentiating the trailing edge of the positive square wave will greatly reduce plate current in V3. Thus, the negative spike will appear across R9, which develops the output of the stage.

The negative output trigger pulse is fed directly to the variable delay circuits and to the sweep gate circuit through K14B, on normal operation.

Fixed Delay and Modulator Trigger Circuits

The fixed delay circuit consists of an input differentiating network (C10 and R11), a switch tube, and an integrating network in its plate circuit. The switch tube V4 is maintained near zero bias by returning the grid to B-plus through R11.

The modulator trigger consists of a blocking oscillator with provisions for taking an output from both the plate and cathode circuits. The oscillator is biased below cutoff in static condition by the negative voltage divider network formed by R15 and R17.

The positive square wave from the master trigger multivibrator is applied to the grid of V4 through the differentiating network. Since V4 is already conducting heavily, the positive spike formed by the leading edge of the square wave input has no appreciable effect on the tube's output. However, the negative spike, formed by the trailing edge of the input square wave, cuts off V4. With tube current cut off, the plate voltage would normally rise to B-plus. However, it should be noted that C11 is connected in series with R19 between the plate and ground. Thus, an integrating network is formed by R13, R19, and C11.

As the plate voltage rises, based on the RC time of R13, R19, and C11, a positive-going sawtooth voltage is fed to the grid of V5. As this sawtooth voltage continues to increase, it will overcome the negative 52 volts on its grid, thus driving the tube into conduction. When conduction begins, the circuit operates as any triggered blocking oscillator. The time required to bring the grid of V5 up to cutoff is determined by the RC time of R13, R19, and C11, and the static state bias on V5. This is the delay time which is fixed at 8μ sec. by the size of the components shown in figure 5-7.

The modulator trigger outputs consist of a negative spike fed to the range marker gate circuit, and a positive spike which is used to control the firing of the modulator. Note that capacitor C13 is connected between pin 1 of T1 and ground. It is used to broaden this waveform by reducing the slope of the output pulse, thus insuring positive triggering of the range marker gate.

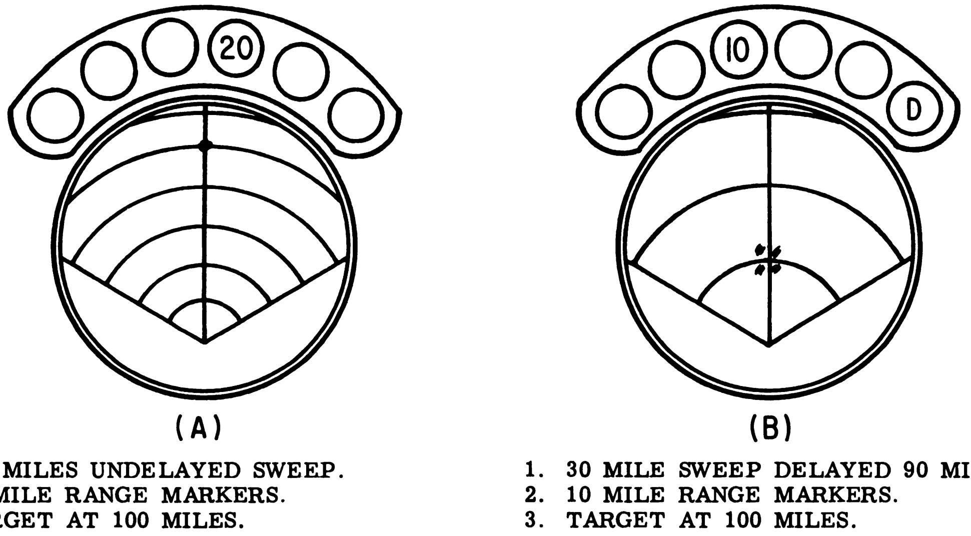
VARIABLE DELAY CIRCUITS

The purpose of variable delay circuits in aviation fire control radars is to provide the various time delays necessary between the operation of two or more circuits. They may be used to provide better target discrimination on the radarscope as illustrated in figure 5-9. In figure 5-9 (B), this is accomplished by delaying the start of the sweep for an interval corresponding to 90 miles of radar range after the transmitter has fired. Then a 30-mile sweep (a faster sweep), is triggered, resulting in the 100-mile target appearing in the center portion of the 30-mile delayed sweep. The faster sweep will also make the target appear larger for better discrimination.

Phantastron delay circuits are used extensively in aviation fire control equipment. Thus, to aid in understanding the variable delay circuits, a basic phantastron circuit is explained, followed by a discussion of a typical delay circuit.

Basic Phantastron Delay Circuit

The phantastron circuit is a medium precision delay circuit used to delay a timing pulse.



(A)

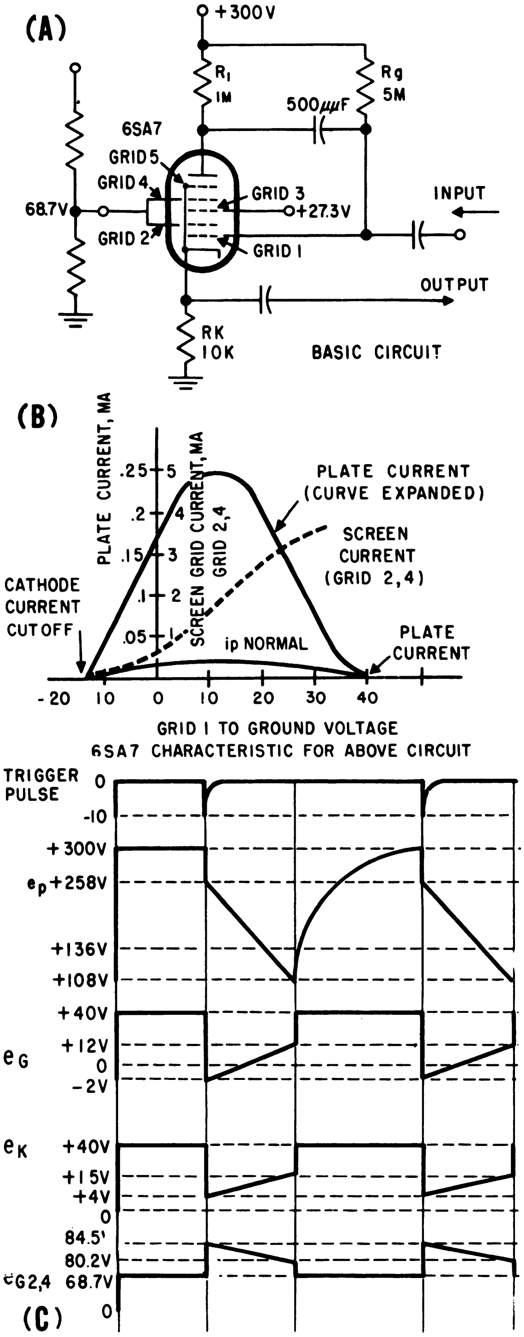
1. 120 MILES UNDELAYED SWEEP.
2. 20 MILE RANGE MARKERS.
3. TARGET AT 100 MILES.
4. TARGET COVERS 1 MILE AREA.
5. TARGET AREA TO SWEEP LENGTH - 1/120.
6. TARGET SMALL AND UNDEFINED. THEREFORE POOR TARGET DISCRIMINATION.

(B)

1. 30 MILE SWEEP DELAYED 90 MILES.
2. 10 MILE RANGE MARKERS.
3. TARGET AT 100 MILES.
4. TARGET COVERS 1 MILE AREA.
5. TARGET AREA TO SWEEP LENGTH - 1/30.
6. TARGET 4 TIMES LARGER AND WELL DEFINED. THEREFORE BETTER TARGET DISCRIMINATION.

AQ. 13

Figure 5-9. –Radarscopes showing time delay.



AQ. 14

Figure 5-10. - Phantastron circuit. (A) Basic circuit; (B) 6SA7 characteristic curve; (C) phantastron circuit voltage waveforms.

Its operation and output are very similar to the one-shot multivibrator circuit discussed in chapter 8 of Basic Electronics, NavPers 10087-B. The phantastron circuit is quite stable under normal power supply voltage fluctuations because its operation depends on the fact that there is a specific d-c voltage relationship between the tube elements. Any variation of source voltage varies the voltage between the tube elements in the same proportion, causing a minimum change in the voltage relationship since all voltages are supplied by dividers across the same voltage source. The phantastron has the unique advantage over the multivibrator delay circuits in that the pulse width, or delay, varies directly with one of the applied d-c voltages. This control by a d-c voltage makes remote control feasible at any distance through unshielded power cables since there is no signal present in the control circuit.

Study the basic phantastron circuit and its associated waveforms shown in figure 5-10. This circuit is never free running and is usually triggered by a negative pulse at the control grid (grid No. 1). Consider first the conditions before the trigger pulse arrives. Grids 2 and 4, which are tied together inside the tube, are connected to a voltage divider from plus 300 volts. The normal output of the divider is 86 volts. But with zero control grid voltage and 86 volts on grid 2, 4 ma of current will flow to grid 2. This additional current in the voltage divider drops grid 2 to 68.7 volts. Grid 3 is connected to a voltage divider which sets its voltage at 27.3 volts. This grid does not draw current because it is negative with respect to the cathode. The current through the 10K cathode resistor is 4 ma. Since the cathode is 40 volts above ground, the grid 3 to cathode voltage is 40 - 27.3 = 12.7 volts. When grid 3 is more than 12 volts negative with respect to the cathode, it prevents electrons from passing it in their journey to the plate. Therefore, since the minus 12.7 volts is beyond plate-current cutoff for grid 3, no electrons will reach the plate. Thus, the plate voltage is plus 300 volts. The grid is connected to E_{bb} through a 5-megohm resistor. A very small grid current flows through the cathode resistor, but the grid voltage may be considered the same as the cathode voltage. Therefore, the difference in potential between grid 1 and the cathode voltage is zero. Grid 5, the suppressor grid, is connected to the cathode and has no part in the operation of the circuit other than performing the normal function of a suppressor grid.

The next factor to consider is the similarity between the phantastron and the start-stop circuit. You can consider the 6SA7 phantastron tube as a tube within a tube. The cathode, grid 3, and plate are equivalent to the first triode in the start-stop circuit. No plate current flows to the plate and the "first-tube" is cut off. The cathode, grid 1, and grid 2 form another triode which is comparable to the second tube of the flip-flop multivibrator. As mentioned previously, this triode is conducting. Consequently, any voltage change, which will cause plate current to flow in the triode that is cut off, will start a regenerative switching action.

You can best understand the action of the phantastron when it is triggered by dividing it into three successive phases. The first phase is an extremely rapid change which ends at a first balance point. The second phase is a slow linear change which ends at a second balance point. The third phase is the recovery of the circuit to the pretrigger condition.

The trigger pulse must have the proper polarity and amplitude to bring grid 3 above cutoff. A negative pulse of 10 volts amplitude is shown. When this is applied to grid 1, the grid 1 voltage will drop to 30 volts. Cathode follower action will cause the cathode voltage to drop to 30 volts along with the grid. At this point, examine the relation between the cathode and grid 3. Their voltage difference is 27.3 minus 30, or minus 2.7 volts. Grid 3 is not negative enough to prevent electron flow to the plate, and plate current will flow as soon as this grid-to-cathode voltage drops below 12 volts. Regenerative action starts with this plate current flow. The plate current through R_L causes a drop of plate voltage. Grid 1 is capacitively coupled to the plate, so the grid becomes more negative. This drops the cathode voltage still more, which in turn further reduces the voltage difference between grid 3 and cathode. The current to the plate increases, the plate voltage drops, and the grid is driven farther in the negative direction.

Note that the plate current increase is not an overall increase in current with a negative-going grid. The negative-going grid decreases the total current. But the resultant decrease in cathode voltage lowers the voltage between grid 3 and the cathode, which allows current to flow to the plate at the expense of the screen current. Grid 3 controls the division of current between the plate and screen grid. Grid 1 controls the total current. So grid 1 decreases the total current, while grid 3 allows the plate current to increase and causes the screen current to decrease quite rapidly. The characteristic curve for the 6SA7 (fig. 5-10(B)) shows the relation. In plotting these curves, a d-c voltage was applied to grid 1 of the circuit in the illustration and varied from minus 20 volts to plus 40 volts. The dotted curve shows the resultant screen current while the other curve shows the plate current. Note that plate current increases by a small amount while screen current decreases a large amount as grid 1 goes negative. The sum of the two currents is the cathode current. It is decreasing because the small current increase is more than overcome by the large decrease.

The regenerative effect just explained is similar to the cutting off of the first multivibrator tube by the second tube. The cutting off process, however, does not go that far in the phantastron, because if the current to the plate were stopped, the plate voltage would have to rise, and this action would be the opposite to the desired feedback. The rapid increase of current to the plate ends at the first balance point. This balance occurs when the negative-going grid 1 voltage decreases the overall current so much that the plate current cannot continue to increase. Grid 3 is unable to divert enough electrons to the plate to maintain the increase of plate current. This occurs when grid 1 has dropped to a minus 2 volts, and the plate has dropped 42 volts before the balance point is reached. Each of these voltages is shown in the curves, under the trigger pulse. The grid voltage has dropped to minus 2 volts. Since this is a 42-volt change, caused by the plate, the plate curve shows a 42-volt drop to 258 volts. The cathode voltage drops, due to the decrease in screen current, until with minus 2 volts on the grid, the current is 0.4 ma. The voltage at grids 2 and 4 has gone up because the screen current is decreased, reducing the drop across the voltage divider and raising voltage to 84.5 volts.

Now consider the action resulting from the starting of the second phase. The grid voltage e_g rises as the 500-$\mu\mu$f capacitor starts to discharge through R_g. At this time the grid voltage is minus 2 and the capacitor discharges from 300 to 260. The grid end of the grid resistor becomes more positive. This increases the plate current, starting another drop in plate voltage. Grid 3 is not involved directly in this stage as it is straight triode action between the plate, grid 1, and the cathode that affects the circuit operation. The plate voltage drop has an effect opposite to that of the discharging capacitor and thereby is degenerative in action. The capacitor discharges, the grid goes positive, plate current increases, plate voltage drops, tending to make the grid go negative. But the plate cannot drop enough to exceed the positive charge at the grid because it is the positive grid voltage that causes the plate voltage drop. So the plate voltage change counteracts only part of the effect of the capacitor discharge, slowing the discharge considerably. This negative feedback keeps the capacitor discharge in the most linear part of the exponential curve.

The discharge continues at a linear rate, as shown by the plate voltage curve illustrated in figure 5-10 (C). The increase in current raises the cathode voltage to 15.5 volts, and the grid 1 voltage is raised to plus 12 volts before the second balance point is reached.

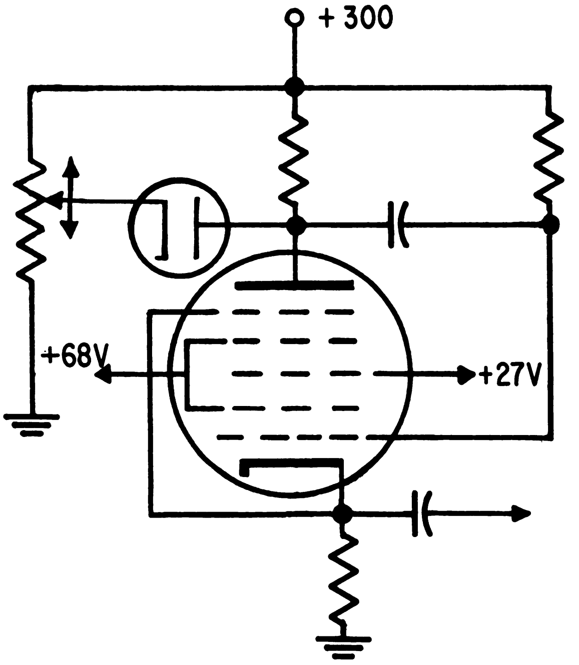
Remember that during all this time, the screen grids (2 and 4) have been continually drawing current at an increasing rate. As the plate voltage continues to fall, there is a minimum point where the screen's current has risen sufficiently and the plate voltage has dropped to the point where the cathode potential is now high enough, in relation to the fixed potential on grid 3, to prevent any further increase in plate current. This occurs at about 108 volts on the plate. This point is also the peak of the plate current characteristic (fig. 5-10 (B)). To the right of this peak, the plate current decreases and the screen current continues to increase. The screen grid's increasing current raises the cathode bias; thus the plate current stops increasing and levels off. This leveling off initiates the rapid switchover to recover the circuit to pretrigger condition.

When the plate current levels off, the voltage stops decreasing at the plate. With the counteracting effect of the plate drop removed, the capacitor discharge raises the grid 1 voltage at a very rapid rate. The positive-going grid 1 increases the current from the cathode, which raises the cathode voltage. This has the same effect as making grid 3 more negative; so grid 3 reduces the current to the plate. Actually, it is dividing the increasing current in favor of the screen grids. The screen current increases tremendously while the plate current is actually decreased. The plate voltage starts to go in the positive direction. This is coupled to the grid by the 500-$\mu\mu$f capacitor to make it go in a positive direction. The cathode voltage is further increased, which brings grid 3 closer to cutoff, reducing the plate current more and raising the plate voltage. This regenerative action continues until grid 3 is beyond cutoff, stopping plate current completely. During this regenerative action, the grid voltage has increased as fast as the plate voltage. But when the grid reaches plus 40 volts, the plate current reaches zero and the grid no longer affects the plate voltage. Thus, as the grid voltage jumps from 12 to 40, the plate voltage curve shows a 28-volt jump from 108 to 136 volts. When the grid voltage reaches a constant value, the plate rises only as fast as the capacitor can recharge along a slow exponential curve up to plus 300 volts. The cathode voltage rises immediately with the grid voltage while the screen grid voltage drops at recovery time because of the increased screen current.

Now consider the circuit from the viewpoint that it is ready for the next trigger pulse. The duration of the output negative pulse on the cathode is fixed in the circuit shown. This pulse width is determined essentially by the RC in the grid 1 circuit, the plate voltage, and the gain of the triodes involved.

The duration of the pulse is generally made variable by applying a d-c voltage to the plate from a potentiometer. The circuit is as shown in figure 5-11. The potentiometer can select any voltage from 0 to plus 300 volts. A diode is inserted in series to disconnect the phantastron plate from the lower-resistance potentiometer during the operation of the circuit. Before the trigger pulse, the plate voltage and voltage at the arm of the potentiometer are the same because the load resistor is so large and the current from the potentiometer so small that there is little voltage drop in the diode plate. When the circuit operates, the plate voltage drops immediately, the diode plate becomes less positive than its cathode, and diode current stops. The potentiometer-diode curcuit has no further effect on the operation of the phantastron.

To see how the potentiometer affects the pulse width, study the effect of varying the position of the potentiometer contact. With the plate voltage at plus 300 volts, the situation is as previously described. But when this plate voltage is reduced to plus 240 volts by means of the potentiometer, the pulse width is decreased. The plate voltage drops the same 42 volts at the time of the trigger pulse since the grid drops 42 volts to the first balance point. Then the slow linear voltage decrease occurs. The slope



AQ. 15

Figure 5-11. -Changing pulse width phantastron circuit.

of this decrease is the same regardless of plate voltage. This terminates at the same 108 volts as the 300-volt waveshape. So the amount of linear decrease is less, which decreases the time required to reach 108 volts. If the potentiometer is set so the plate voltage is 170 volts before the pulse, the plate will again drop 42 volts, and follow the same slope to 108 volts. Again the amplitude of the slope is decreased so the slope time is decreased.

Since the initial drop, the slope, and the final value do not change, the decrease in pulse length is linear with the decrease in plate voltage. This relation holds over the range from the full plate voltage (300 volts in this case) to a minimum of 108 plus 42, or 150 volts. This is the minimum voltage point because the initial 42-volt drop would bring it down to 108 volts, or zero pulse width. Since the pulse width for the previous example used is 1,395 microseconds, the pulse width is variable from 0 to 1,395 microseconds.

Typical Phantastron Delay Circuit

The previous circuit is satisfactory for short delays, but when the delay becomes nearly as long as the time between pulses, the long exponential recovery of the plate circuit overlaps the next pulse. With the circuit not yet fully recovered, the second pulse may not trigger the circuit. Therefore the circuit is modified for long delay periods as shown in figure 5-12. The change is primarily the addition of a triode (V-20) between the plate and grid of the phantastron tube. This triode is called a cathode follower. Before the trigger pulse arrives, the grid of the cathode follower is at the plate potential and is drawing current. Thus, its cathode is within a fraction of a volt of the grid voltage. Therefore the coupling capacitor C30 has the plate voltage on one side and the grid voltage on the other. This is similar to the circuit in figure 5-10.

When the trigger pulse drops the plate voltage, the grid voltage of the cathode follower (and consequently its cathode voltage) goes down. The coupling capacitor C30 makes grid 1 go in the negative direction. Thus by cathode follower action, the grid drops along with the plate.

At the completion of delay time, plate current is again cut off and the plate tries to return to its static potential. In the two phantastron circuits just discussed, the rate of plate voltage rise was limited by the RC time of the plate load resistor and the plate-to-grid coupling capacitor. However, in the circuit shown in figure 5-12, the phantastron plate is connected directly to the grid of the cathode follower. Since the grid can follow the plate potential, there is no delay in the phantastron plate rise, and the coupling capacitor C30 may charge through the relatively low plate resistance of V20.

The potentiometer R74 is incorporated to provide a maximum delay adjustment. This adjustment, normally a screwdriver adjustment, determines the RC time in the phantastron grid circuit.

RANGE SWEEP GENERATING CIRCUITS

The range sweep in a radar set is of paramount importance for the correct presentation of target information. To accomplish this, a sawtooth voltage or current of proper amplitude and slope must be supplied to the indicator's deflection system. This discussion will include a typical range sweep circuit used for generating a linear sawtooth of the proper amplitude and time duration. The same circuit is used to generate the sweep for more than one

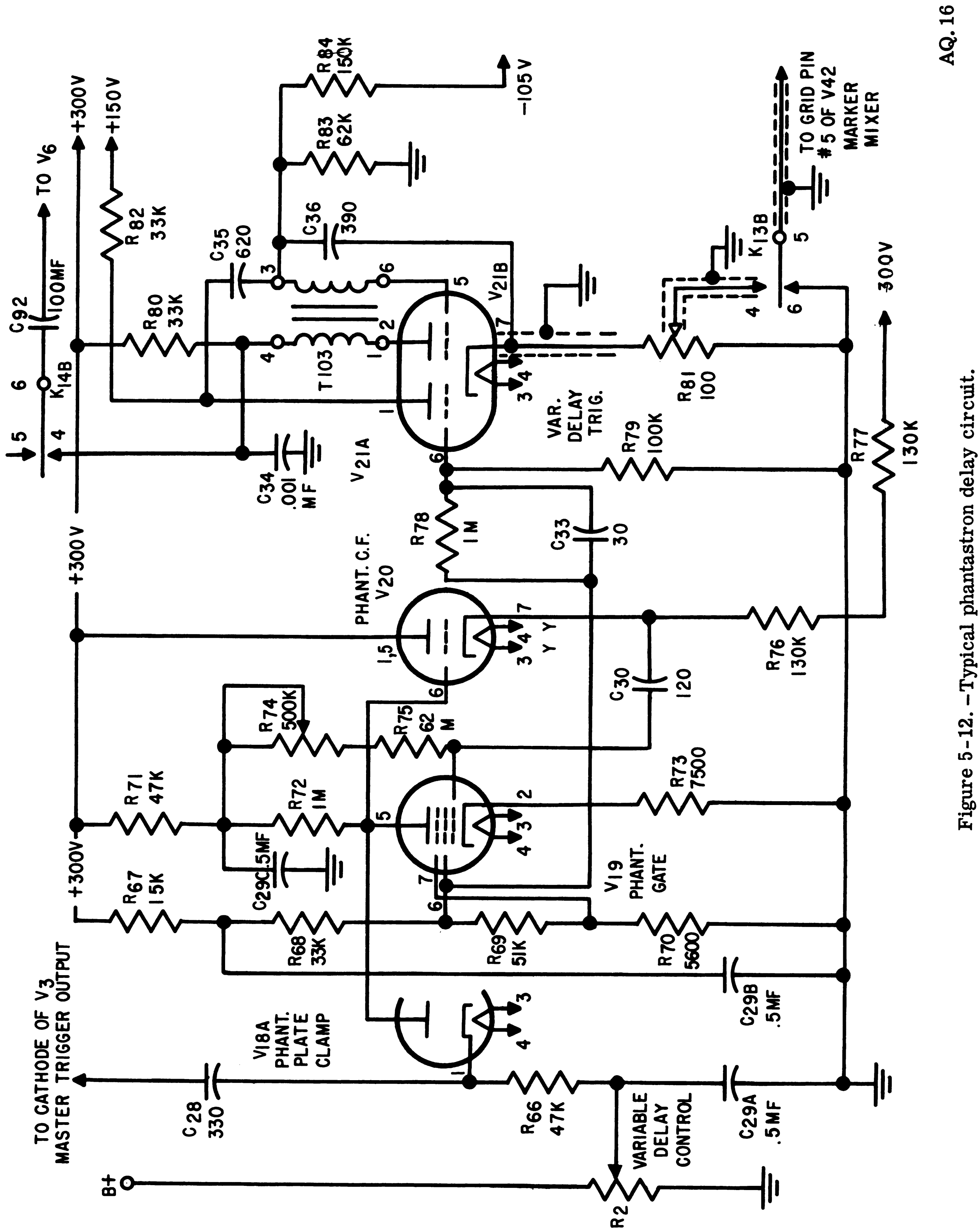


Figure 5-12.—Typical phantastron delay circuit.

range, and yet maintain the same physical sweep length on the scope. Since the basic circuits involved in the sweep generator are discussed in chapter 12 of Aviation Fire Control Technician 3 and 2, NavPers 10387, only its actual operating condition is explained in detail in this chapter.

Sweep Gate Circuit

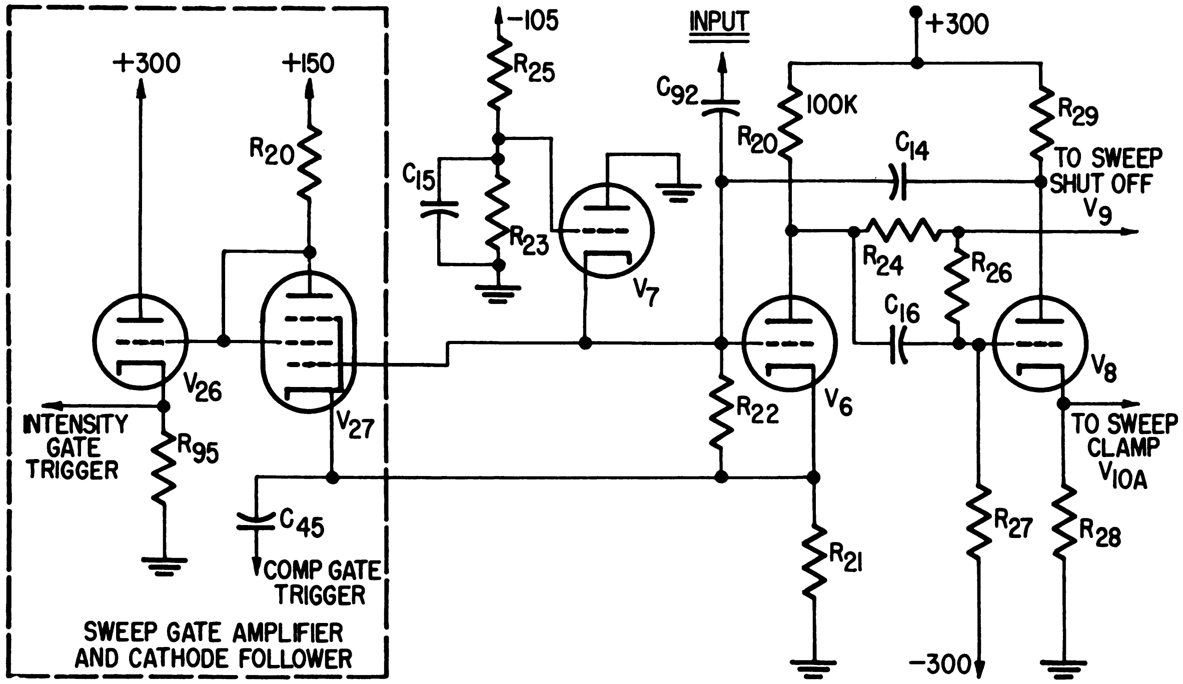
The sweep gate circuit consists of a one-shot multivibrator, V6 and V8 (fig. 5-13), a negative grid clamper V7, and two sweep gate amplifiers V26 and V27. (NOTE: V26 and V27 are discussed later in the chapter.) It should be noted that V8 is cut off in static condition by the voltage divider network in its grid circuit and that V6 is conducting. The circuit is triggered by a negative pulse which is applied to the grid of V6. It should be recalled from the discussion on the timer block diagram that the sweep gate circuit is triggered by a negative pulse from either the master trigger output on normal operation, or the variable delay circuit on time delay operation.

The negative input trigger pulse drives V6 toward cutoff, causing a rise in its plate voltage and a drop in its cathode voltage. This plate voltage rise is coupled to the grid of V8, driving V8 into conduction. The resulting drop in plate voltage is coupled back to the grid of V6 as in any one-shot multivibrator. However, the negative grid clamper does not permit the grid of V6 to be driven below an approximate negative 23 volts.

The action of V7 and the sweep shutoff circuit (fig. 5-14) controls the duration of the output pulses from the sweep gate circuit. (NOTE: The output from the sweep gate determines range sweep time which is discussed later in this chapter.)

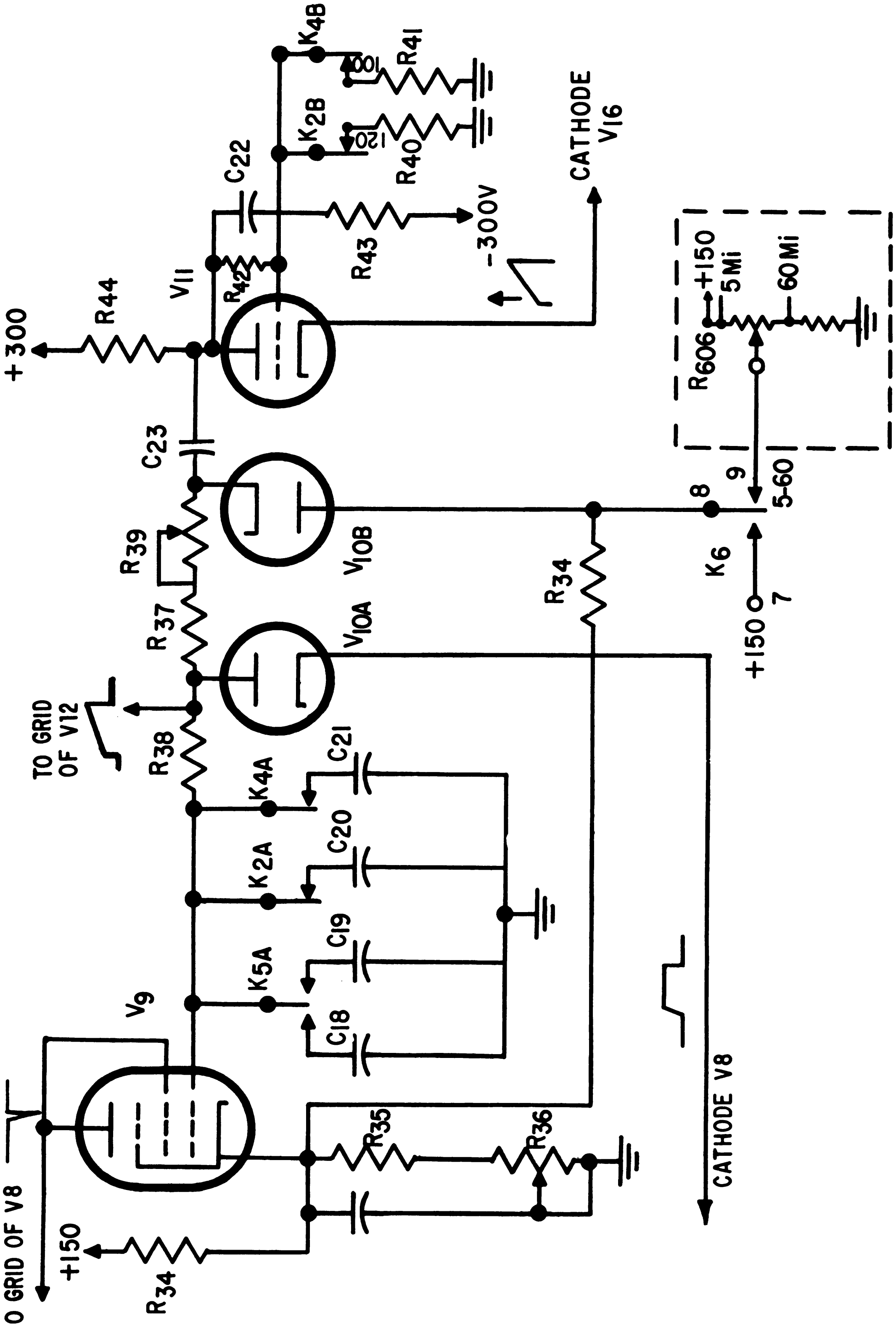
The outputs of the sweep gate circuit are as follows:

1. A negative square wave (generated by conduction of V8 through R29 and capacitively coupled to the grid of V6) from the grid of V6 which is fed to the grid of sweep gate amplifier V27.
2. A negative square wave from the cathode of V6 which is used to trigger the compensating gate circuit.
3. A positive square wave from the cathode of V8 which is used as a gating voltage. The



AQ. 17

Figure 5-13.–Sweep gate circuit.



AQ. 18

Figure 5-14.—Sweep clamp, shutoff, charging clamp, and bootstrap amplifier.

relationship of the output waveforms to the master timing pulse is shown by waveforms (1), (2), and (3) of figure 5-15.

The sweep gate amplifier V27 and sweep gate output V26 circuits are discussed later in this chapter with the intensity gate circuit.

Sweep Clamp, Shutoff, Charging Clamp, and Bootstrap Amplifier

Before considering the overall operation of the circuit illustrated in figure 5-14, the functions it performs are discussed. The circuit may be divided into three stages with each stage performing a separate function.

The first stage consists of the RC network composed of C18 to C21, R37, R38, R39, and the two diodes V10A and V10B. The RC network is used to generate a sawtooth waveform for use as a range sweep voltage. V10A and V10B function to clamp the upper plates of the sweep capacitors (C18 through C21) at near ground and provide a means of eliminating the clamping action during sweep time.

The stage V9 controls the amplitude of the sawtooth voltage waveform. It also generates a pulse which cuts off the sweep gate output voltage when the sawtooth voltage reaches the desired amplitude.

It should be remembered from the previous chapter that at any instant the charge on a capacitor depends on the RC time of the network and the applied voltage. For the fixed ranges (all ranges except 5-60 miles), range is controlled by switching in various size capacitors, and the applied voltage is held at a positive 150 volts. In the variable range (5-60) mode of operation, the applied voltage is varied by the variable range control R606.

Referring to figures 5-13 and 5-14 note that without an input signal, current (electron flow) will flow from ground up through R28 to the cathode of V10A, from cathode to plate of V10A, through R37 and R39 to cathode of V10B, from cathode to plate of V10B, and to pin 8 of relay K6. Pin 8 of K6 is connected to a positive 150 volts through pin 7 when the equipment is operating on a fixed range. When operating on a variable range, pin 8 is connected to the variable range control R606 which forms a voltage divider network between ground and a positive 150 volts.

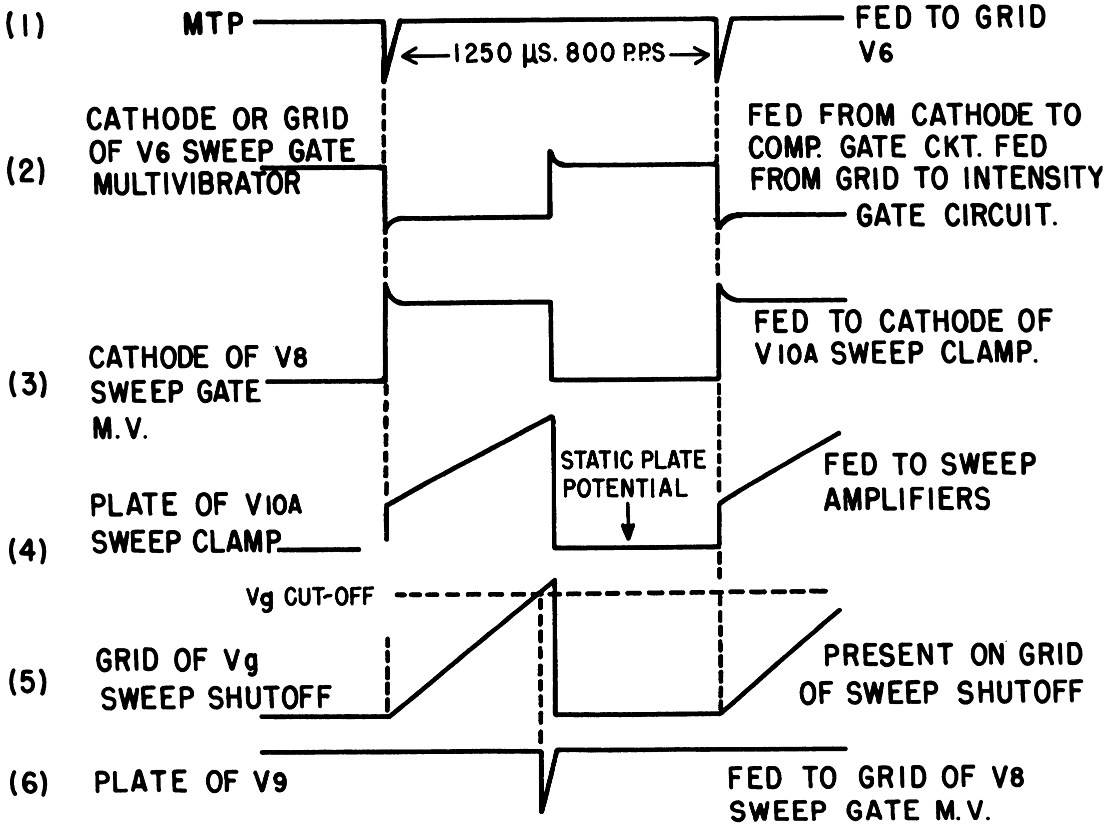
The path from K6 through R34 to the top of R35 has negligible effect because of its high resistance. The static current maintains the plate of V10A at a relatively low potential which also determines the static voltage across capacitors C18 thru C21. (The relative size of R28 to R37 plus R39 clamps the plate of V10A slightly above ground.) The sweep cutoff tube V9 is biased beyond cutoff by a positive potential applied to the voltage divider network in its cathode circuit. The cathode potential of V9 is important since it determines sweep amplitude which indirectly controls sweep time.

Now consider the operation of the circuit when a signal is applied. (For the following discussion refer to waveforms illustrated in figure 5-15.) A positive square wave taken from the cathode of V8 is applied to the cathode of V10A. It should be remembered that this square wave is generated by the sweep gate multivibrator. With the cathode of V10A now more positive than its plate, V10A is effectively removed from the circuit. The sweep charging capacitors (C18 thru C21) may now charge at an RC rate as determined by the RC network being used. As the sweep capacitors charge toward 150 volts (assume fixed range operation), the grid of V9 will also rise at the same rate. When the grid voltage rises sufficiently to overcome its cathode bias, V9 will conduct, producing a negative-going pulse of sufficient amplitude to cut off V8. Since the conduction of V8 provided the voltage source which cut off the clamping circuit (V10A), the circuit will now return to its static condition.

The time required for V9 to conduct was determined by its static cathode potential and the RC network being used to generate the sawtooth voltage waveform (assuming a constant sweep amplitude). Therefore sweep time is controlled by varying the values of resistance and capacitance in the charging circuit on all fixed ranges.

The relationship of the MTP to the waveforms of the range sweep generating circuits is shown in figure 5-15. Waveform (3) is the positive square wave which disables the clamper V10A. It should be noted that waveform (4) is a sawtooth superimposed on a low amplitude square wave. The square wave portion, called a jump voltage, is developed across R38 when V10A is cut off. Waveform (5) should be studied noting that when the sawtooth voltage reaches cutoff, waveforms (2), (3), and (4) are also terminated.

The output of the sweep charging circuit, a positive sawtooth on a pedestal, taken from the plate of V10A is directly coupled to the grid of the sweep amplifier V12. (NOTE: The operation of V11 has been omitted purposely at this time; however, it is discussed later in this chapter.) This output waveform is shown as waveform (1) of figure 5-16.


(1)
MTP
←1250 µS. 800 P.P.S→
FED TO GRID V6
(2)
CATHODE OR GRID OF V6 SWEEP GATE MULTIVIBRATOR
FED FROM CATHODE TO COMP. GATE CKT. FED FROM GRID TO INTENSITY GATE CIRCUIT.
(3)
CATHODE OF V8 SWEEP GATE M.V.
FED TO CATHODE OF V10A SWEEP CLAMP.
(4)
PLATE OF V10A SWEEP CLAMP
STATIC PLATE POTENTIAL
FED TO SWEEP AMPLIFIERS
Vg CUT-OFF
(5)
GRID OF Vg SWEEP SHUTOFF
PRESENT ON GRID OF SWEEP SHUTOFF
(6)
PLATE OF V9
FED TO GRID OF V8 SWEEP GATE M.V.

AQ. 19

Figure 5-15.—Waveforms of the sweep generating circuits.

Sweep adjustments are provided to allow the technician a means of compensating for any slight variations in circuit parts. R36, located in the cathode V9, is a screwdriver adjustment for setting the sweep amplitude. R39 is a similar adjustment, but it permits a fine adjustment of the sweep slope or sweep time.

SWEEP AMPLIFIER CIRCUITS

You should now be familiar with how the sawtooth sweep is generated and how it is used as a time base for the measurement of range. However, this sawtooth must be amplified before it is applied to the deflection system of the indicator. The sweep amplifier circuits also provide a means of feedback to improve the linearity of the sweep voltage. The feedback voltage is taken from the sweep driver stage and fed to the bootstrap amplifier V11.

The basic circuits utilized in the sweep amplifier circuits have been discussed in detail in Basic Electronics, NavPers 10087-B. Therefore, only the operation of the sweep amplifier and its waveforms are discussed. Figure 5-16 is an illustration of the waveforms throughout the sweep amplifying chain. Reference to waveforms illustrated are by number as shown. Figure 5-17 is the schematic of the sweep amplifying circuits and should be referred to for the following analysis.

As stated previously, the positive sawtooth on a pedestal is coupled directly from the plate of the sweep clamper V10A to the grid of the first sweep amplifier V12 (waveform (1), fig. 5-16). Note that the cathode of V12 is returne to ground through the sweep driver's cathod resistor. This provides degenerative feedbac which improves the linearity of the amplifyin circuits. This should not be confused with th feedback loop through the bootstrap amplifie to the sweep generator. Feedback within th

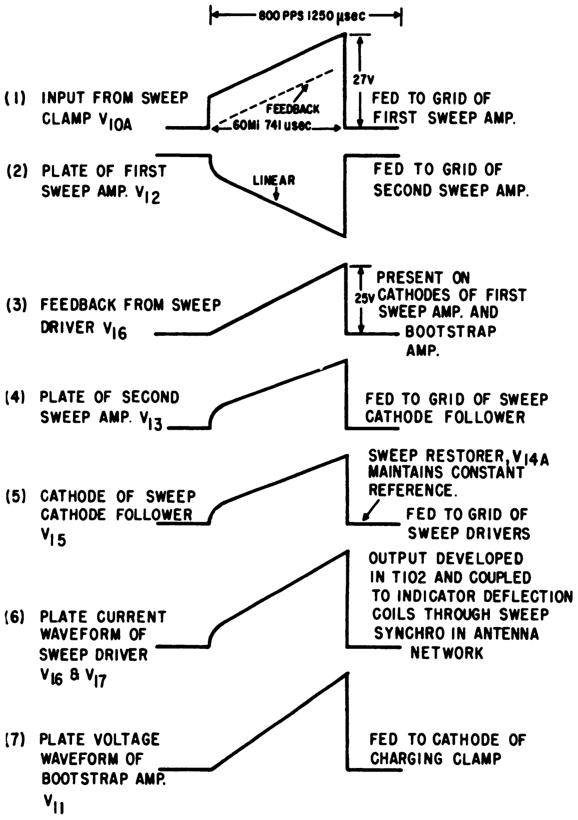

800 PPS 1250 μsec
27V
FEEDBACK
60MI 741 usec
(1) INPUT FROM SWEEP CLAMP V_{10A}
FED TO GRID OF FIRST SWEEP AMP.
(2) PLATE OF FIRST SWEEP AMP. V_{12}
LINEAR
FED TO GRID OF SECOND SWEEP AMP.
(3) FEEDBACK FROM SWEEP DRIVER V_{16}
25V
PRESENT ON CATHODES OF FIRST SWEEP AMP. AND BOOTSTRAP AMP.
(4) PLATE OF SECOND SWEEP AMP. V_{13}
FED TO GRID OF SWEEP CATHODE FOLLOWER
(5) CATHODE OF SWEEP CATHODE FOLLOWER V_{15}
SWEEP RESTORER, V_{14A} MAINTAINS CONSTANT REFERENCE.
FED TO GRID OF SWEEP DRIVERS
(6) PLATE CURRENT WAVEFORM OF SWEEP DRIVER V_{16} & V_{17}
OUTPUT DEVELOPED IN T102 AND COUPLED TO INDICATOR DEFLECTION COILS THROUGH SWEEP SYNCHRO IN ANTENNA NETWORK
(7) PLATE VOLTAGE WAVEFORM OF BOOTSTRAP AMP. V_{11}
FED TO CATHODE OF CHARGING CLAMP

Figure 5-16. –Waveforms of the sweep amplifying chain. AQ. 20

sweep amplifiers aids in eliminating distortion that may be generated within the sweep amplifire circuits. The feedback voltage is illustrated by waveform (3). The relative amplitudes of the two signals applied to V12 should be noted. Thus, the output of V12, because of the feedback voltage, has been greatly reduced.

A linear negative sawtooth on a pedestal is coupled to the grid of the second sweep amplifier V13. The oscillation suppression circuit, consisting of C25 and R48 in the grid circuit of V13, acts as a low impedance path for high frequency oscillations. (NOTE: A sudden change in input voltage such as the trailing edge of waveform (1) may shock-excite an amplifier into oscillating.) The second sweep amplifier also amplifies and inverts the signal as shown by waveform (4). Its output, a positive sawtooth on a pedestal, is fed to the grid of the cathode follower V15.

The cathode follower is used to match the high impedance output of the second sweep amplifier to the low input impedance of the sweep driver. In static condition, V15 is biased negative by the voltage divider network in its grid circuit. However, with the plate of V15 connected to a positive 150 volts and its cathode connected through R53 to a negative 300 volts, it will conduct and bias V16 at approximately minus 40 volts. The diode V14A is used as a

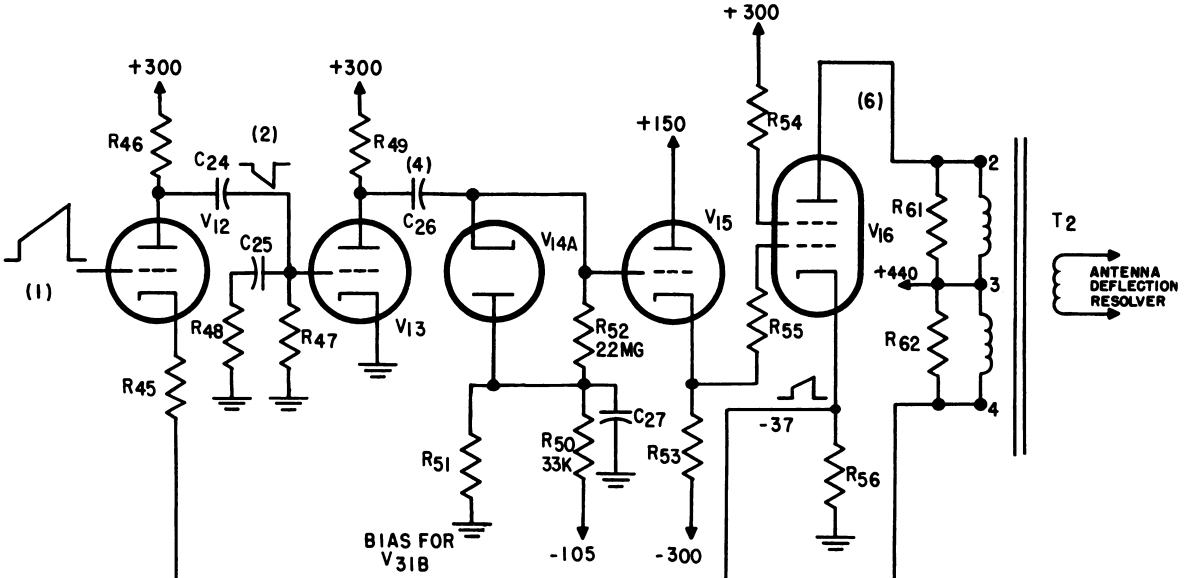


Figure 5-17. –Sweep amplifying circuits. AQ. 21

clamper to return the grid to its static potential following each sawtooth input.

The sweep driver receives the positive trapezoidal voltage (sawtooth on a pedestal) from the sweep cathode follower. As the slope of the waveform is reduced (longer ranges), the pedestal amplitude is also reduced.

The output transformer T2 is the plate load for the sweep driver. As shown in waveform (6), a linear positive sawtooth of current appears in its primary with each input. It is combined with a signal from the compensating gate driver which is discussed later in this chapter. Resistors R61 and R62 are in parallel with the primary of T2 and are used to dampen oscillations of the transformer. Degenerative feedback resulting from the unbypassed cathode resistor R56 also aids in reducing oscillations as well as providing a source of signal which is fed back to earlier stages. A sweep reference level signal is also fed from this point to the sweep compensating gate circuit.

Bootstrap Amplifier

Now that you have a general idea of the operation of the sweep circuits, the action of the bootstrap amplifier is explained. For the following discussion refer to figure 5-14.

The input to the bootstrap amplifier (applied to the cathode) is a linear positive sawtooth voltage from the cathode of the sweep driver. The amplitude of the input signal is proportional to the output current of the sweep driver. The output of the bootstrap amplifier is also a positive sawtooth voltage which is slightly greater in amplitude than its input signal. This output is coupled to the sweep generating circuit through C23.

In explaining the operation of the sweep generating circuit, it was stated that the charge path of the sweep capacitors was through V10B and relay K6 to the voltage source. This statement is not true when considering the operation of the bootstrap amplifier. Since coupling capacitor C23 plays an important part in the operation of the circuit, consider in detail its static condition. The left plate of C23 is connected to the cathode of V10B and will be at plus 150 volts on all but the 5-60 mile range. The right plate is connected to the plate of V11 which is at approximately plus 80 volts during static condition. The capacity of C23 is much greater than that of the capacitors used by the sweep generating circuit on any range. Therefore, should the charge on C23 be used as a source of voltage during the time the sweep is being generated, the sweep charging current would have negligible effect on the voltage across C23.

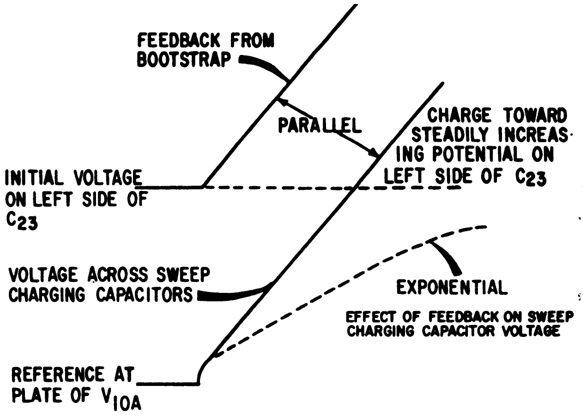
(NOTE: The use of a charged capacitor as a source of voltage for short periods of time has been employed in numerous cases in radar equipment.) Let us now consider the operation of the sweep generating and bootstrap amplifier circuits. When the pulse from the sweep gate multivibrator cuts off V10A, the sweep capacitors will begin to charge as stated in the previous expanation. However, as the sawtooth is being generated, it is also being fed back to the bootstrap amplifier. This causes the voltage of the right side of C23 to rise. This rise in voltage is coupled to the sweep generating circuit by C23 which causes V10B to be cut off. From this point on to the end of sweep time, the charge on C23 and sawtooth on the plate of V11 will be the source of charging potential for the sweep generating circuit.

The sawtooth on the plate of V11 is of the same amplitude as that appearing on the plate of V10A. This increase results in a constant effective charging potential during sweep time for maximum linearity. Figure 5-18 illustrates graphically the voltage relationship during sweep time.

At the termination of sweep time, V10A and V10B conduct, resettling or clamping the potential of the capacitors in the circuit.

COMPENSATING GATE GENERATING CIRCUITS

As stated previously, the purpose of the compensating gate circuit is to generate


FEEDBACK FROM BOOTSTRAP
PARALLEL
CHARGE TOWARD STEADILY INCREASING POTENTIAL ON LEFT SIDE OF C_{23}
INITIAL VOLTAGE ON LEFT SIDE OF C_{23}
VOLTAGE ACROSS SWEEP CHARGING CAPACITORS
EXPONENTIAL
EFFECT OF FEEDBACK ON SWEEP CHARGING CAPACITOR VOLTAGE
REFERENCE AT PLATE OF V_{10A}

AQ. 2

Figure 5-18. –Effect of feedback on sweep charging capacitor voltage.

gating voltage that will cause the indicator's electron beam to be reset at the end of each range sweep, thus insuring that each trace on the indicator will start at the same point. The compensating gate circuit consists of a trigger generator, a multivibrator, a gate clamp, an amplifier, and a driver. It also utilizes two other diode clamp circuits to aid in maintaining proper reference potentials.

Compensating Gate Trigger

The compensating gate trigger V28 (figure 5-19) is a single-swing blocking oscillator. It is biased beyond cutoff by the voltage divider network consisting of R97 and R98 in its grid circuit. It receives as its input a square wave from the sweep gate circuit. (NOTE: The relationship of this square wave to sweep time is important and is illustrated by waveforms (1) and (2) of figure 5-20.) However, the square wave is differentiated by C45, R97, and R98. The waveform as it appears at the grid of V28 is shown by waveform (3). The negative spike does not affect the operation of the circuit since the stage is cut off when it arrives. However, the positive spike drives the grid above cutoff which starts the oscillator to operating.

Once the grid is driven above cutoff, the oscillator operates as any single-swing blocking oscillator. The circuit has two outputs–(1) a negative spike taken from the remaining transformer secondary winding which is fed to the range marker circuit, and (2) a negative spike developed by the surge of plate current through the plate load resistor. The latter output is used to synchronize the compensating gate multivibrator V29 and V30.

Compensating Gate Multivibrator

This multivibrator is used to generate a positive square wave for gating the compensating gate clamp circuit. When the trigger pulse from the trigger generator arrives, V30 is conducting and V29 is cut off. The negative trigger pulse is coupled from the plate of V29 through one of the grid capacitors to the grid of V30.

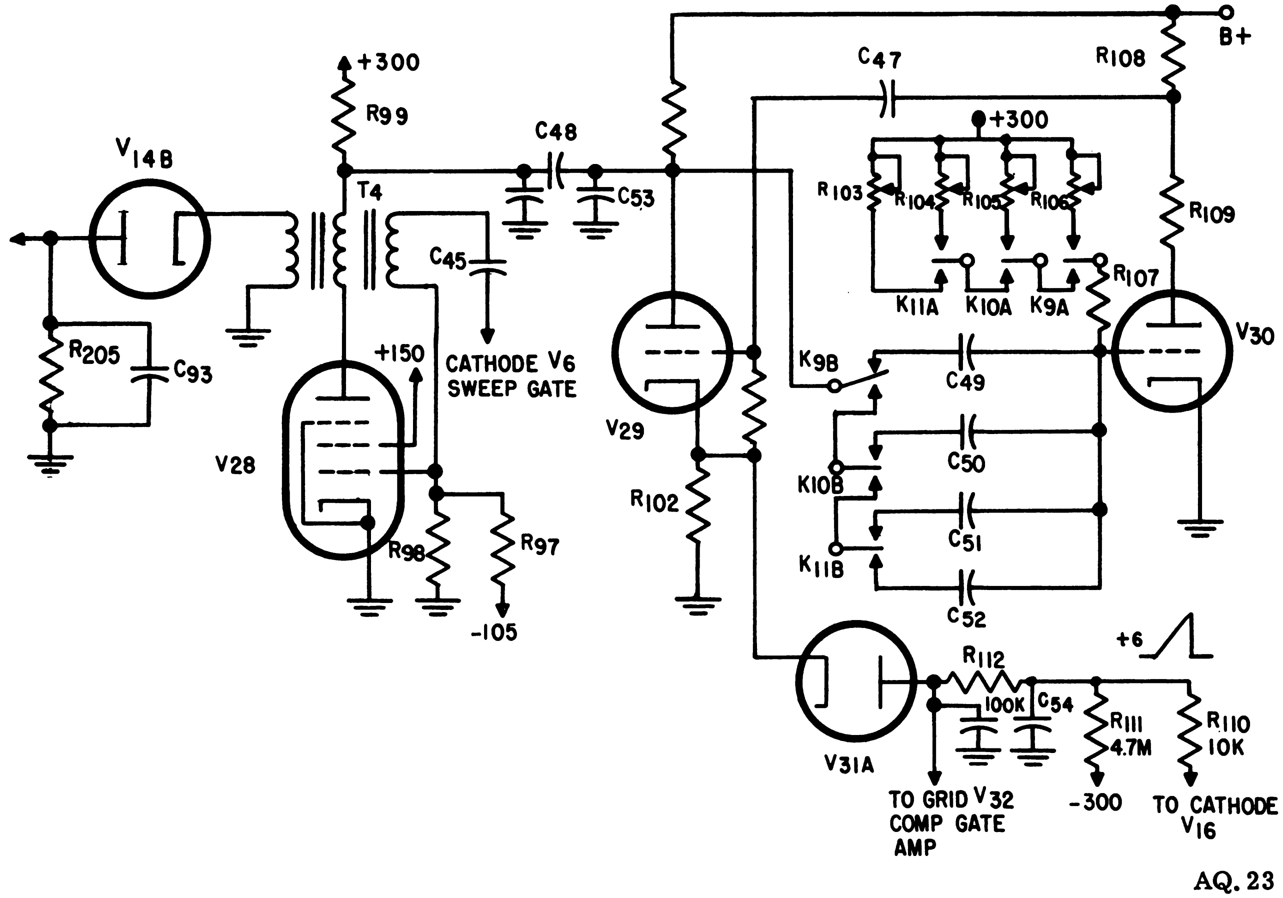
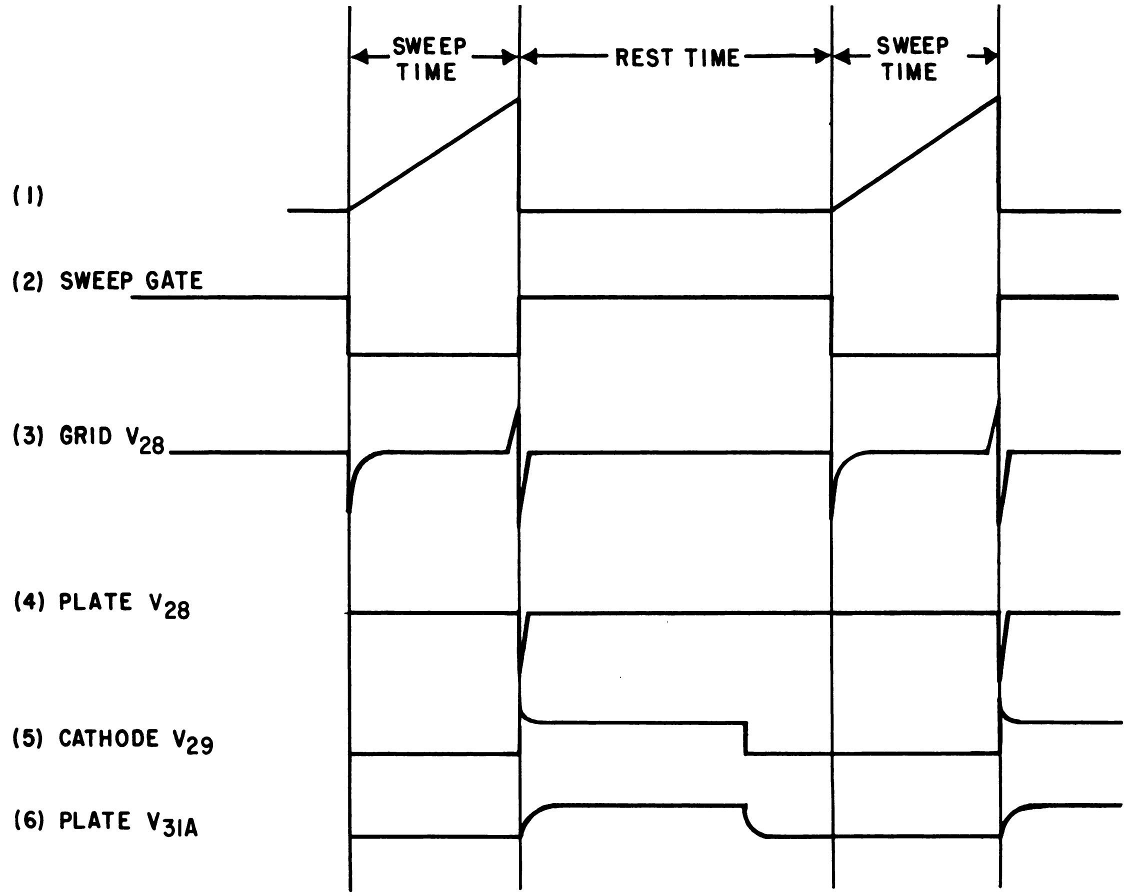


Figure 5-19.–Compensating gate circuit, Part 1.



AQ. 24

Figure 5-20. –Compensating gate waveforms.

The pulse cuts off V30 and its rise in plate voltage is coupled back to the grid of V29, driving it to saturation. The time V30 remains cut off depends on the values of resistance and capacitance in the grid circuit. Relays K9, K10, and K11 are used to control the RC time in the grid circuit of V30 which, in turn, are controlled by the PRF selection circuit. Thus, the frequency of the multivibrator output is controlled by the sweep gate circuit and the pulse width varies with the PRF of the equipment.

The output of the multivibrator, a positive square wave–the leading edge of which coincides with the end of sweep time–is shown by waveform (5) in figure 5-20. Like the output of the sweep gate multivibrator, this square wave is used as a gating pulse by the compensating gate clamp circuit.

Compensating Gate Clamp

Before discussing how the compensating gate clamp circuit utilizes the gating pulse, first consider its static state. Referring to figure 5-19, note that R111 and R110 form a voltage divider between minus 300 volts and the cathode of V16 which is approximately positive 6 volts in static condition. The plate of V31A is held slightly positive (approximately 1 volt) with a small current flowing through R102 and V31A.

When the equipment is operating, a sawtooth voltage of approximately 20 volts in amplitude is developed across the sweep driver cathode resistor. This 20-volt increase will increase the charge on C54 and the current through V31A. The voltage to which C54 will charge will be proportional to the amplitude and duration of the sweep sawtooth.

As the sawtooth is terminated, the compensating gate multivibrator produces a positive square wave (discussed previously) which cuts off V31A. This effectively connects the capacitor C54 to the grid of the first compensating gate amplifier. Thus, the voltage across C54 which is proportional to sweep amplitude is used to generate the compensating gate voltage.

A summary of the action of the circuit is as follows:

1. C54 is charged to a voltage that is proportional to the amplitude of the sweep sawtooth.
2. At the end of sweep time the compensating gate circuit is triggered and a square wave gating pulse is generated.
3. This square wave is used to disconnect V31A from the circuit.
4. The voltage across C54 is now applied to the grid of the first amplifier.
5. At the end of the gating pulse, V31A conducts and the circuit is ready for its next sweep.

Study the waveforms in figure 5-20 carefully and insure that the time relationship of each waveform is understood.

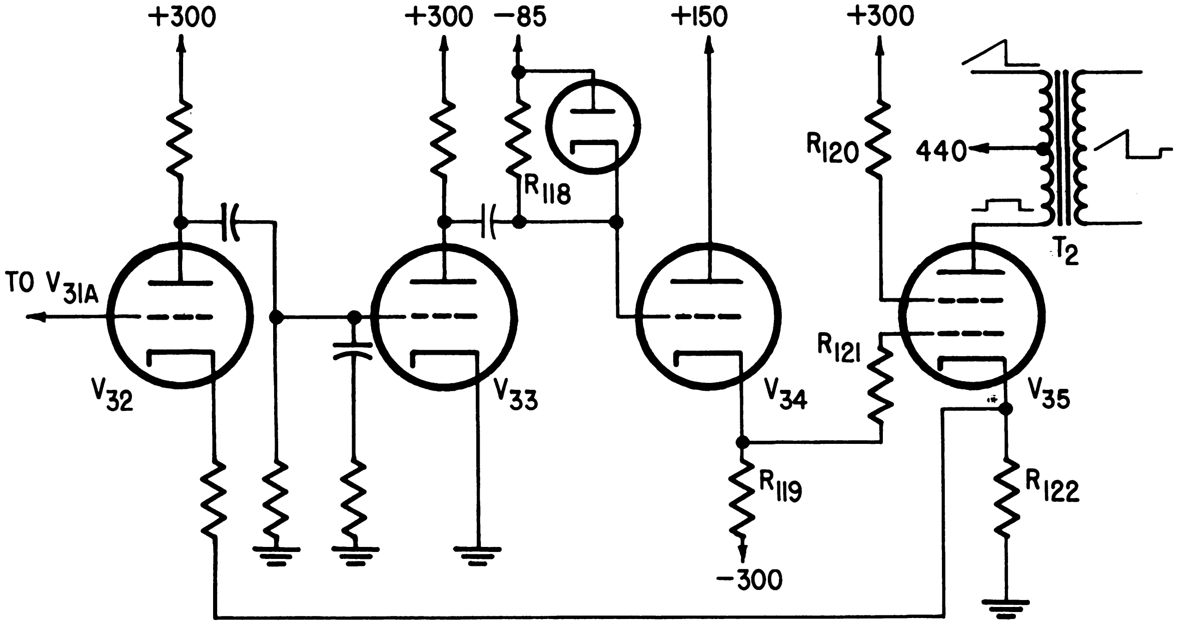
Compensating Gate Amplifier

The compensating gate amplifier consists of two voltage amplifiers and a cathode follower. (See fig. 5-21.) Their function is to amplify the compensating gate pulse to the proper level to drive the compensating gate driver. The amplifier is similar to the sweep amplifier discussed in the previous section and therefore is discussed only briefly.

The positive gate on the grid of V32 is amplified and inverted, and fed to the grid of V33. The gate is again amplified and inverted and appears as a positive gate on the grid of the cathode follower V34. The diode V31B is employed as a clamper to insure that each gate starts from the same static potential. The grid of the cathode follower is connected to a negative 85 volts, permitting an input signal of considerable amplitude without distortion. It should be noted that inverse feedback from the cathode of the driver to the cathode of the first amplifier is used to improve the shape of the compensating gate output.

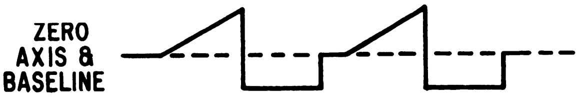
Compensating Gate Driver

The driver V35 (fig. 5-21) is identical to the sweep driver V16 (fig. 5-17). Its output is a



AQ. 25

Figure 5-21. –Compensating gate circuit, Part 2.



AQ. 26

Figure 5-22. –Range sweep sawtooth and compensating gate voltage waveform.

square wave of the same area as the sweep waveform. Although the compensating gate is of the same polarity as the sweep voltage, it is inverted since it appears at the opposite end of the primary winding of T2. Thus, the compensating gate is combined with the range sweep sawtooth voltage as shown in figure 5-22.

INTENSITY GATE CIRCUIT

The purpose of the intensity gate circuit is to provide a means of unblanking and blanking the indicator at the proper time. However, before discussing the intensity gate circuits, consider the circuits that provide it with a trigger or gating pulse. When the equipment is using ALT. DEL. or T.D., the intensity gate circuit is triggered by the output of the sweep gate multivibrator. However, this pulse is not usable without prior amplification. This is accomplished by the sweep gate amplifier and the sweep gate cathode follower.

Sweep Gate Amplifier and Cathode Follower

The sweep gate amplifier V27 is conducting during static condition. (See fig. 5-13.) A negative square wave is applied to its control grid during sweep time, cutting it off. This produces a positive-going square wave which is direct-coupled to the grid of the sweep gate cathode follower V26. Its output, taken from the cathode, is fed to pin 4 of relay K15B. Thus, when the equipment is in ALT. DEL. or T.D. operation, the intensity gating circuit is controlled by a positive square wave of the same time relationship as the range sweep sawtooth.

Intensity Gate Output

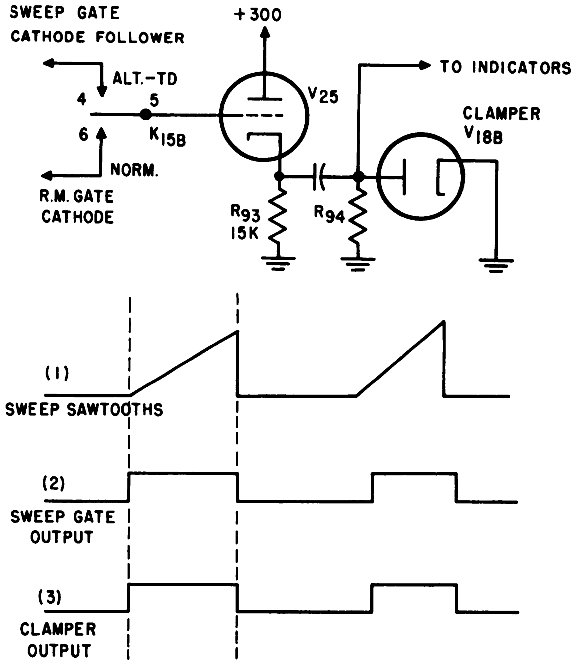
The intensity gate output V25 (fig. 5-23) is a cathode follower whose input comes from either the sweep gate output (just discussed) or the range marker gate circuit, depending on the type of operation employed. In either case the operation of the intensity gate stage is identical. Its input is a positive-going square wave, beginning and ending with sweep time, which causes V25 to conduct heavily. The increased current flow develops a positive square wave at the output, which is coupled to the intensity gate clamp circuit.

Intensity Gate Clamp

The intensity gate clamp V18B is a negative clamper. It clamps the positive portion of the square wave from V25 at the zero reference voltage. This effectively provides a negative square wave for blanking the indicator's sweep when there is no sweep voltage fed to the indicator (flyback). Waveform (3) illustrates the waveform fed to the indicator.

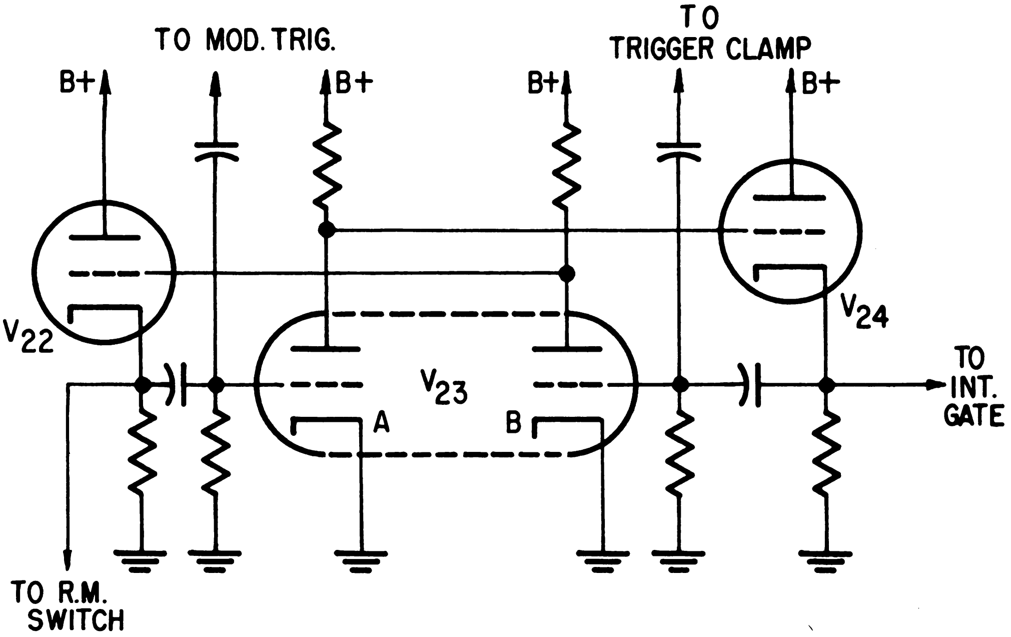
RANGE MARKER GATE CIRCUIT

The function of the range marker gate circuit is to furnish the gates to operate the range marker circuit and, in normal operation, furnish the intensity gate circuit with a gate for unblanking the indicator. These gates operate



AQ. 27

Figure 5-23. –Intensity gate circuit and waveforms.



AQ. 28

Figure 5-24. -Range marker gate circuit.

in synchronism with the modulator trigger pulse, so that the range markers are started and the indicator is unblanked in coincidence with the firing of the transmitter.

Referring to figure 5-24, the range marker gate is a free-running multivibrator (about 20 Hz until triggered) which utilizes a cathode follower between the plate and grid in each of the feedback circuits. Actually its period during free running is so long, as compared to the incoming pulse, that for the instant of triggering, the multivibrator has all the characteristics of a bistable multivibrator. To simplify the explanation of the circuit's operation, consider that V23A is conducting and that V23B is cut off. A negative trigger from the modulator trigger circuit is applied to the grid of V23A which synchronizes the start of the range marker gate circuit with the transmitter. This negative pulse cuts off V23A and causes a positive pulse to be applied to the grid of V24 which also appears on its cathode. The positive pulse on the cathode of V24 is capacitively coupled to the grid of V23B which drives it into conduction.

The positive pulse is also fed to the intensity gate circuit which is used for unblanking the indicator on normal operation. It should be remembered that both the intensity gate circuit and the range marker generator should be cut off except during sweep time.

The positive pulse applied to the grid of V23B causes a drop in its plate voltage which is direct-coupled to the grid of V22. V22's cathode voltage is also reduced a proportional amount which is coupled back to the grid of V23A, keeping it cut off. A second output, a negative pulse, is taken from the cathode of V22 and fed to the range marker generator.

Since it is desired to operate the range marker circuit only for the duration of the sweep, a stop trigger is provided to return the range marker gating circuit to its normal condition. The stop trigger, a negative pulse, is applied to the grid of V23B, cutting it off. As in any basic multivibrator of this type, the rise in plate voltage of V23B is coupled back to start V23A conducting.

The waveforms and their relationship to the master timing pulse are shown in figure 5-25.

RANGE MARKER GENERATING CIRCUIT

The purpose of the range marker circuit is to produce electronic signals that appear on the

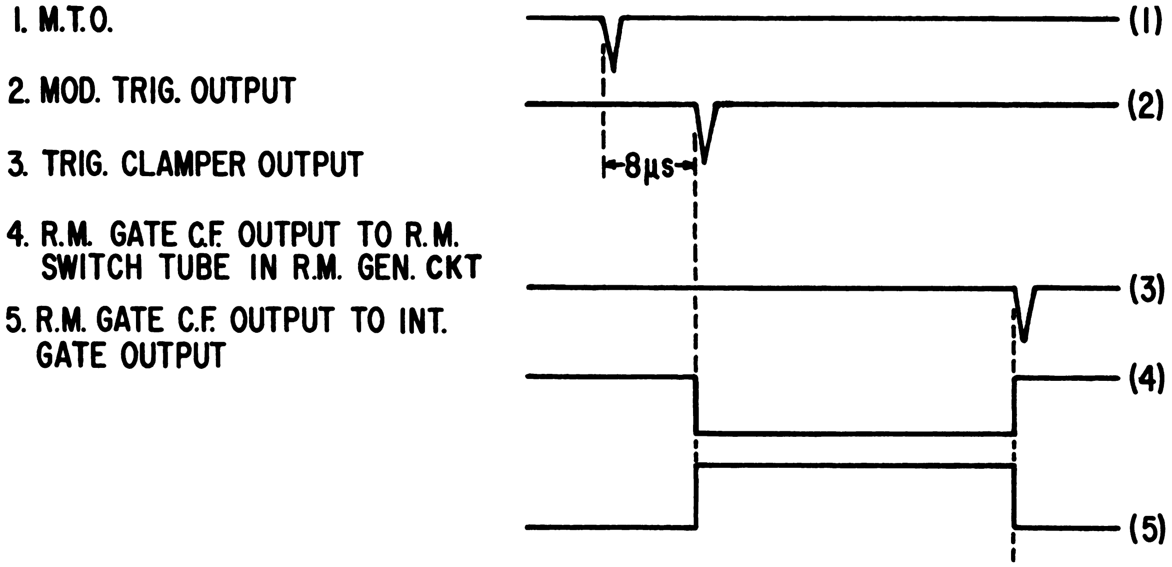

1. M.T.O.
2. MOD. TRIG. OUTPUT
3. TRIG. CLAMPER OUTPUT
4. R.M. GATE C.F. OUTPUT TO R.M. SWITCH TUBE IN R.M. GEN. CKT
5. R.M. GATE C.F. OUTPUT TO INT. GATE OUTPUT
8μs
(1)
(2)
(3)
(4)
(5)

Figure 5-25. –Range marker gate circuit waveforms.

AQ. 29

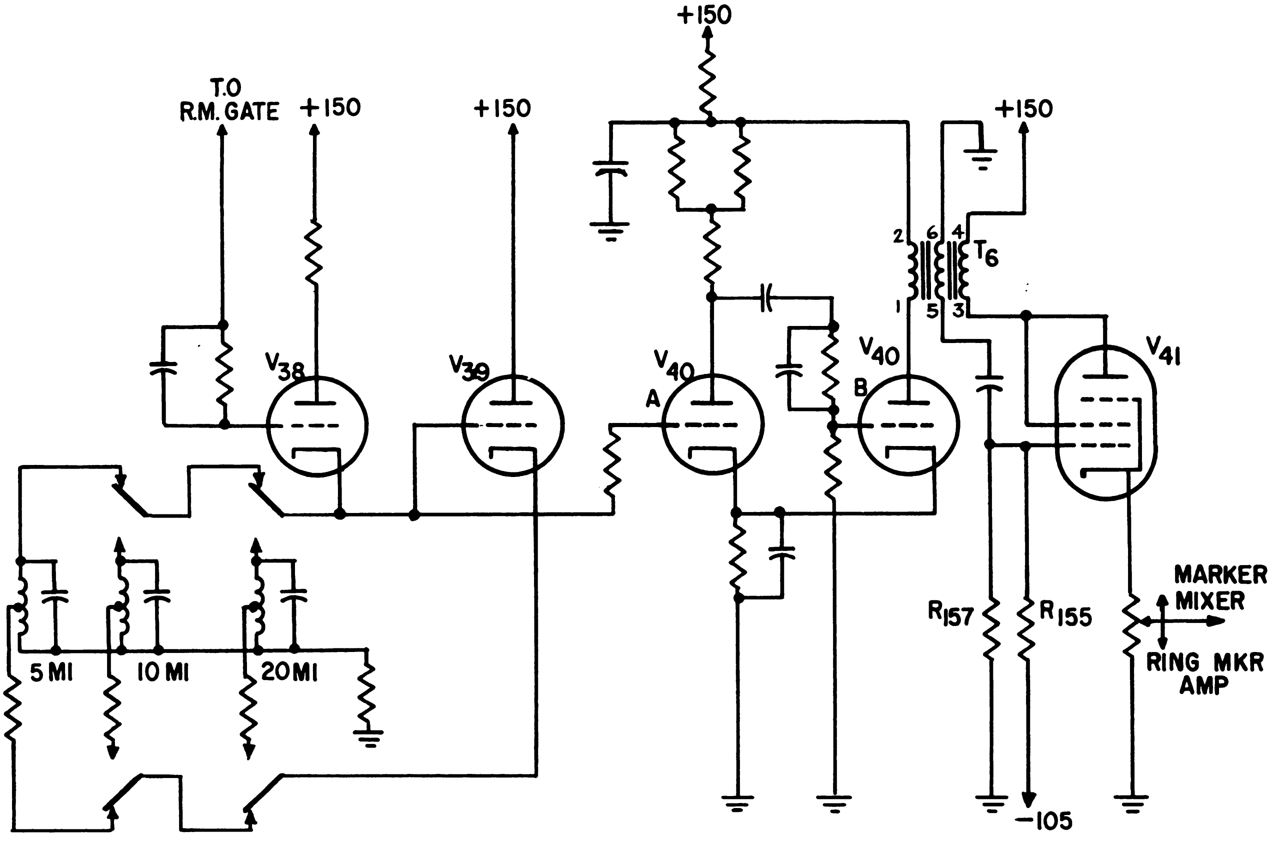


Figure 5-26. –Range marker generating circuit.

AQ. 30

indicator to provide the operator with an indication of distance. They cause bright spots or lines to appear at regular intervals on the indicator.

The range marker generating circuit shown in figure 5-26 consists of the following stages:

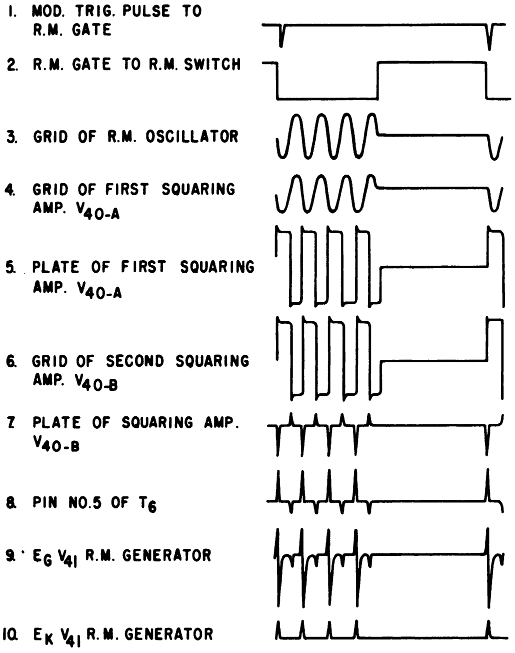
1. Switch tube.
2. Range marker oscillator.
3. Squaring and peaking amplifiers.
4. Range marker generator.

Switch Tube

The switch tube functions to control the operation of the range marker oscillator. It prevents the range marker oscillator from oscillating while in a static condition by acting as a shunt across the tank circuit. A negative square wave from the cathode of the range marker gate cathode follower (waveform (2), fig. 5-27) is coupled to the control grid of the switch tube V38. This drives the switch tube below cutoff, eliminating its shunting effect and allowing the range marker oscillator to oscillate.

Range Marker Oscillator

The range marker oscillator is a modified Hartley oscillator. (For a complete analysis of this type oscillator, refer to chapter 8 of Basic Electronics, NavPers 10087-B.) It should be noted that the oscillator utilizes a separate tank circuit for each output frequency. When the switch tube V38 (fig. 5-26) is cut off, its shunting effect is removed and the oscillator is free to oscillate. These oscillations are taken from the grid of V39 and are applied to the grid of V40A, the squaring amplifier. This output is illustrated by waveform (3) of figure 5-27.


1. MOD. TRIG. PULSE TO R.M. GATE
2. R.M. GATE TO R.M. SWITCH
3. GRID OF R.M. OSCILLATOR
4. GRID OF FIRST SQUARING AMP. $V_{40\text{-}A}$
5. PLATE OF FIRST SQUARING AMP. $V_{40\text{-}A}$
6. GRID OF SECOND SQUARING AMP. $V_{40\text{-}B}$
7 PLATE OF SQUARING AMP. $V_{40\text{-}B}$
8. PIN NO.5 OF T_6
9. E_G V_{41} R.M. GENERATOR
10. E_K V_{41} R.M. GENERATOR

AQ. 31

Figure 5-27. –Waveforms of range marker generating circuit.

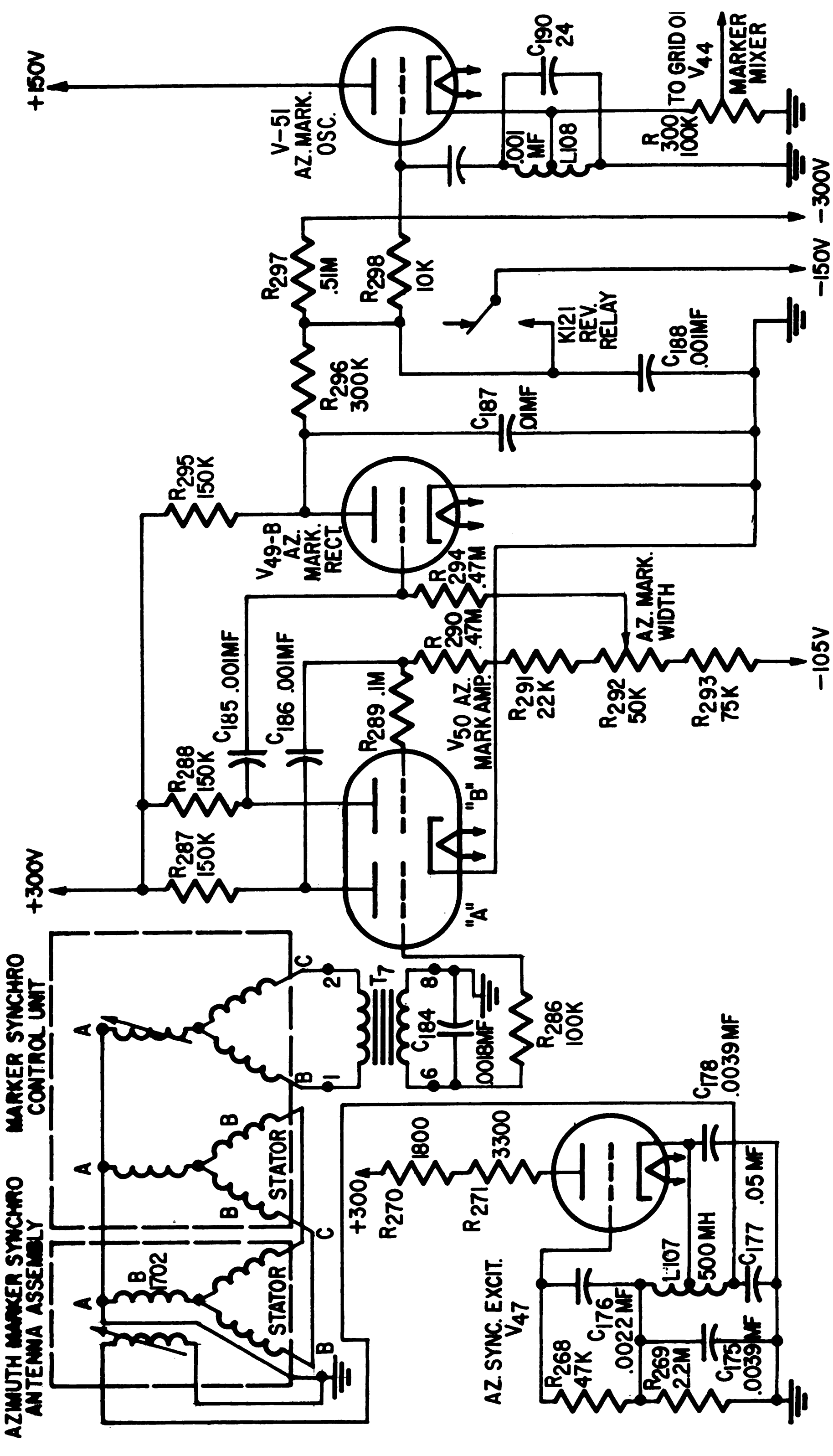
Squaring and Peaking Amplifier

The squaring amplifier V40A (fig. 5-26) is conducting in static condition. However, it is biased to a point that the negative swing of the sine-wave input causes the grid to go beyond cutoff. Its plate voltage rises to B-plus and remains there as long as the negative grid voltage exceeds the cutoff voltage for the stage. (See waveform (5).) The inductive kick of L6 produces an additional voltage spike that causes the output voltage to exceed B-plus. Waveforms (5) and (6) illustrate the spike which appears at the leading edge of each output pulse. The output of the squaring amplifier is fed to the grid of the peaking amplifier V40B. Its output (waveform (7)) is coupled from the tertiary winding to the secondary winding of the blocking oscillator transformer T6, whence it is applied to the grid of the range marker generator tube V41.

Range Marker Generator

The range marker generator V41 (fig. 5-26) is a typical single-swing blocking oscillator. (NOTE: Blocking oscillators are discussed in detail in chapter 8 of Basic Electronics, NavPers 10087-B.) In a static condition, it is held inoperative by the voltage divider network (R-155 and R157) in its grid circuit. Each positive pip from the peaker circuit is applied to V41, producing a series of short pips for each train of oscillations produced by the Hartley oscillator. Since the amplitude of the blocking oscillator output is independent of the amplitude of its synchronizing trigger pulses, each marker pip is of the same amplitude, producing range markers of equal intensity on the indicator. Waveforms (9) and (10) illustrate the input and output of the range marker generator.

Potentiometer R158 in the cathode circuit of V41 allows adjustment of the intensity of the range markers which are applied as positive pips to the grid of the marker mixer circuit.



AQ. 32

Figure 5-28.—Azimuth marker circuit.

AZIMUTH MARKER CIRCUIT

The azimuth marker circuit provides an electronic marker which is used to brighten the trace on the indicator as the antenna crosses a preselected angle. The azimuth marker may be used to assist in measuring the bearing of a target, or as a lubber line in radar bombing operation.

The azimuth marker circuit is somewhat different from the range marker circuit or from any other circuit discussed previously. To facilitate understanding the operation of the azimuth marker circuit, divide it as follows: (1) azimuth marker detector circuits and (2) azimuth marker amplifier and oscillator circuits.

Azimuth Marker Detector Circuit

This circuit consists of a synchro exciter, a marker synchro, and a marker differential synchro. The synchro exciter V47, a Hartley oscillator, produces a 4,000-hertz sine-wave output. As shown in figure 5-28, its output is fed directly to the rotor of the azimuth marker synchro located on the antenna.

Consider the voltage induced in the secondaries of the marker synchro. With the marker synchro rotor as shown, antenna pointing straight ahead, a maximum voltage would be induced in winding A; windings B and C would have an induced voltage of approximately one-half that of A. Note that the voltage in windings B and C is equal and that no voltage difference exists between points B and C. As the rotor is turned in a clockwise direction, the voltage in winding B will increase and the voltage in winding C will decrease. Thus, a voltage difference will now exist between points B and C. If the rotor is turned in the opposite direction, the voltage across B will decrease and the voltage across C will increase. Thus, it should be apparent that there will be a zero output only when the antenna is pointing directly ahead. (NOTE: The antenna is limited to 75° rotation each side of center.)

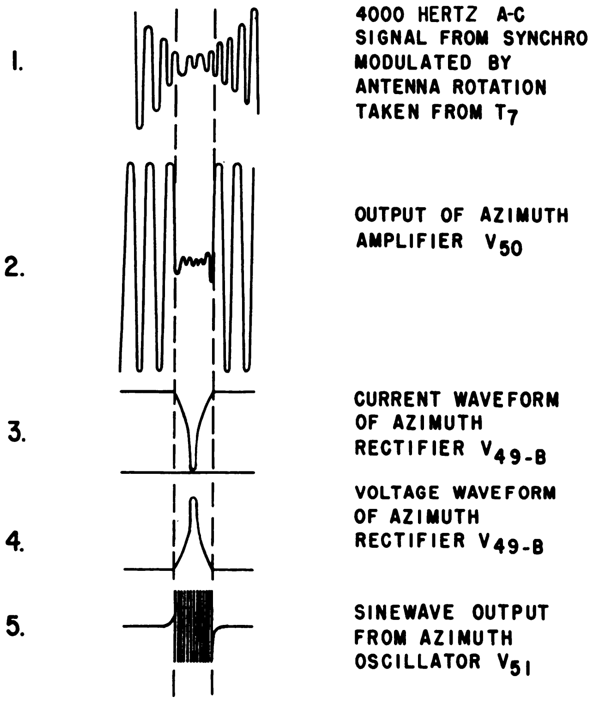
The stator windings of the differential synchro are connected in parallel with the stator windings of the marker synchro. Therefore, the voltage across the respective windings will be equal. With its rotor set at zero, the voltage across each of the differential synchro rotor windings will also be approximately equal to that across the respective stator windings. Thus, if the antenna is positioned as shown and the synchro differential is set at zero as shown, the voltage between pins 1 and 2 of T7 will also be zero.

If the differential synchro rotor is displaced from zero in either direction, a voltage will appear across T7 and the phase of the voltage will be indicative of the direction of rotation. Thus, the zero output or null can be positioned in either direction from dead ahead by simply rotating the differential synchro rotor. In some systems this control may be positioned manually, or it may be positioned electrically in the center of the sector being scanned by the antenna.

The signal developed across the secondary of T7 is fed to the azimuth marker amplifier. This is discussed in the following section. (NOTE: The phase relationship of the input to T7 is unimportant, as the objective of the circuit is to produce a zero output at the desired antenna position.)

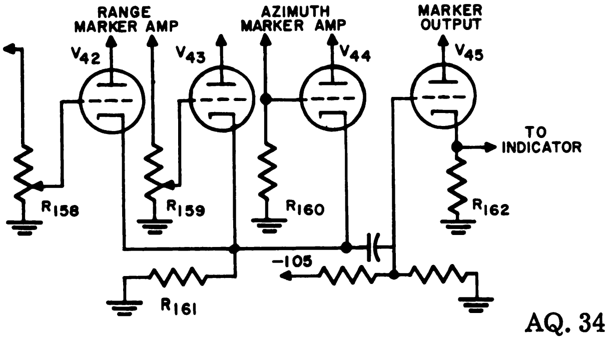
Azimuth Marker Amplifier and Oscillator

The azimuth marker amplifier V50A receives the 4000-hertz modulated signal from T7 (waveform (1) of fig. 5-29). This input is amplified


1.
4000 HERTZ A-C SIGNAL FROM SYNCHRO MODULATED BY ANTENNA ROTATION TAKEN FROM T_7
2.
OUTPUT OF AZIMUTH AMPLIFIER V_{50}
3.
CURRENT WAVEFORM OF AZIMUTH RECTIFIER V_{49-B}
4.
VOLTAGE WAVEFORM OF AZIMUTH RECTIFIER V_{49-B}
5.
SINEWAVE OUTPUT FROM AZIMUTH OSCILLATOR V_{51}

AQ. 33

Figure 5-29. –Azimuth marker circuit waveforms.



AQ. 34

Figure 5-30. –Marker mixer circuit.

and coupled to the second azimuth marker amplifier V50B. This signal is of sufficient amplitude to cause both saturation and cutoff limiting, thus producing a series of square waves.

The squared output signal is applied to the grid of V49B which functions as a plate detector. The output of this detector consists of a current waveform of the same general shape as the envelope of the input signal (waveform (3)). Since the grid bias is variable on V49B, it is evident that variations of the level at which detection occurs will cause variations in the width of the output pulses produced.

The positive swinging output pulses from the detector are direct-coupled to the grid of the azimuth marker oscillator tube V51. The marker oscillator (a modified Hartley) rests in a nonoscillating state. This is accomplished by maintaining the bias at a value below the oscillating point. When the marker pulses (waveform (4)) appear on the grid of the oscillator, it drives the grid sufficiently positive to permit the stage to oscillate. These oscillations (waveform (5)) are taken from the cathode in the form of a comparatively high frequency sine wave, continuing for the duration of the marker pulse. This sine wave is applied to the marker mixer circuit.

MARKER MIXER CIRCUIT

The purpose of the marker mixer circuit is to allow the various types of markers to be mixed and coupled to the indicator for intensity modulation of the scope. It provides an easy means of mixing several input signals with a minimum of interference between the associated circuits and auxiliary fire control equipments.

The marker mixer circuit illustrated in figure 5-30 is composed of three triodes, connected as cathode followers, and the marker output stage which is also a triode and used as a marker output cathode follower.

The inputs to the marker mixer circuit shown in figure 5-30 are range markers and azimuth markers. An additional cathode follower is shown which could be used by an auxiliary equipment such as IFF.

The combined markers are developed across R161 and fed to the marker output stage. The purpose of the output stage is to provide power amplification and match its output impedance to the indicator's input impedance.

MAINTENANCE

The first and foremost item to be considered when performing maintenance on radar synchronizers is the safety of personnel. Operation of radar equipment involves the use of lethal high voltages; therefore, maintenance personnel must observe all safety regulations at all times. Do not change tubes or make adjustments inside the equipment with the high-voltage supply on. Do not rely upon door switches or interlocks for protection. Even with the power controls in the OFF position, dangerous potentials may exist in the circuits because of the charges retained by the capacitors. To avoid casualties, always discharge and ground circuits prior to touching them.

PREVENTIVE

The preventive maintenance of radar synchronizers is largely a matter of alinement and performance checks. Sometimes a check of the equipment alinement in the trouble area will give valuable clues to aid in the location of a malfunction in the system. However, in those instances where replacement of parts leads to misalinement of a circuit (a condition normally determined by the performance check following correction of any trouble), reference should be made to the appropriate part of the alinement procedures contained in the Service Instruction Manual on your particular system. This manual includes all test equipment required, both general and special, as well as the correct procedure and desired results of each check. It also lists probable causes of unfavorable checks in the form of trouble isolation charts or tables.

CORRECTIVE

The defects disclosed during the performance, preflight, postflight, or periodic checks of a synchronizer should be corrected by means of the systems trouble analysis, which is a systematic troubleshooting procedure found in the Service Instruction Manual for the equipment. They are logical and thorough, and are easy to follow. In the troubleshooting procedures, localization of the trouble to a function of the equipment is accomplished first, and is followed by isolation of the trouble to a function within a subcomponent. The purpose of this system is to quickly determine the subcomponent in which trouble exists, and to point out some of the most likely causes for the trouble, particularly parts designed for easy replacement.

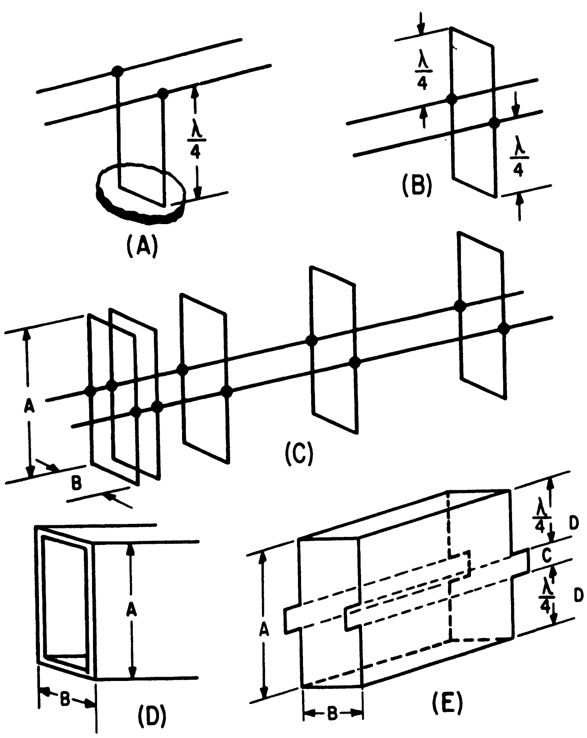
After the trouble has been isolated, maintenance personnel can determine what action, dependent on the time element, should be taken to correct the trouble. To prevent delays in flights, those subcomponents which are defective and which are easily replaceable should be exchanged for components known to be in good operating condition. The defective unit can then be taken to the shop where proper troubleshooting procedures can be followed.

CHAPTER 6

WAVEGUIDE PLUMBING AND CAVITY RESONATORS

WAVEGUIDES

A waveguide is a type of transmission line designed for use in the superhigh frequency (SHF) range. It is used to transmit RF energy from the RF oscillator (magnetron) to the antenna for propagation. The waveguide, a hollow metal tube, is equivalent to a two-wire transmission line supported by an infinite number of quarter-wave shorted stubs. This analogy is illustrated in figure 6-1.



AQ. 35

Figure 6-1. –Shorted quarter-wave stubs in the development of a rectangular waveguide.

Waveguides may be rectangular, round, or oval in shape. This discussion is limited to rectangular waveguides as they are the type most frequently found in aviation fire control radar sets. However, a great deal of the information can be used in the analysis of the other types of waveguides.

Hollow waveguides have no radiation losses and their dielectric losses are too small to be considered. Their copper losses are much smaller than that of coaxial lines. Therefore, they are the best type transmission line for use in the SHF range.

FREQUENCY CAPABILITIES

The capability of a waveguide to transmit different frequencies is determined by its physical dimensions. Referring to figure 6-1 (C), side A must have a minimum dimension of one-half wavelength with respect to the applied frequency. If dimension A is less than one-half wavelength (frequency is low), the supporting stubs (walls of the waveguide) will be less than one-quarter wavelength shorted stubs. A shorted stub less than one-quarter wavelength appears as an inductance to the source. Therefore, when side A is less than one-half wave with respect to the applied signal, the transmission line (the imaginary centerline running longitudinally along dimension A, of figure 6-1 (E)) will no longer appear as a resistive impedance to the signal, but as an inductive reactance. A portion of the signal will be shunted due to the inductive reactance. This characteristic, along with others that are beyond the scope of this discussion, will determine the minimum frequency (cutoff frequency) of the waveguide. The wavelength λ_{co} corresponding to the cutoff frequency is equal to twice the inside width (side A) of the guide; that is, $\lambda_{co} = 2A$.

However, side A may be greater than one-half wavelength with respect to the frequency of the applied signal. If dimension A becomes greater than one-half wavelength (the frequency is increased), the longitudinal centerline of the A dimension will increase in width and take on the appearance of a bus bar, as shown by dimension C of figure 6-1 (E). Dimension D will now be the physical dimension of a quarter wave with respect to the new frequency.

As the frequency of the applied signal is increased, the width of dimension C will increase (the quarter-wave stubs)–dimension D will decrease in physical length. Therefore, the waveguide could theoretically pass an infinite number of higher frequencies as the quarter-wave stubs approached zero length and the bus bar C occupied the entire dimension A. In practice, however, this increase is limited by other factors, and the dimension A of a waveguide is normally constructed to equal about $0.7 \lambda_{co}$.

PHYSICAL LIMITATIONS

As previously discussed, the dimension of side A will be determined by the frequency to be applied to the waveguide. Waveguides are seldom used at frequencies below 3,000 MHz (10 centimeters) due to the physical size requirements of the waveguide. A typical section of waveguide constructed to transmit a 10-centimeter signal has an outside A dimension of 3 inches. To transmit a 1-meter (300 MHz) signal the waveguide would be approximately 30 inches in width. Therefore, waveguides designed for any frequencies lower than 3,000 MHz would be too large for practical applications in airborne equipments.

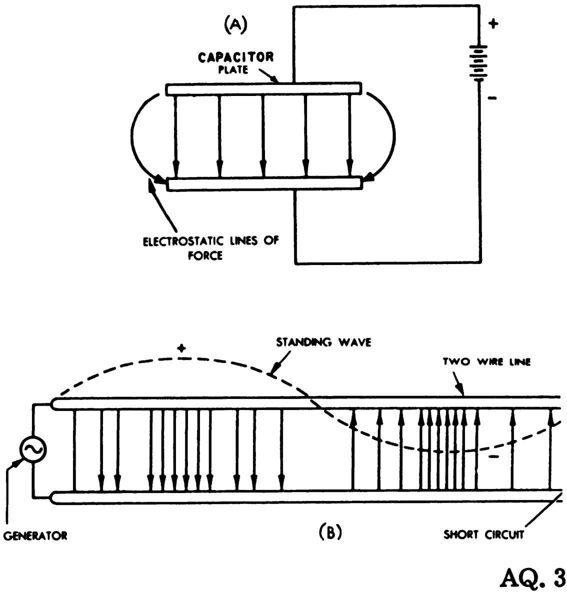
The physical dimension of side B is dependent upon the power the waveguide is required to handle. The power a waveguide can handle is equal to E^2/Z_o with E being the voltage applied and Z_o the characteristic impedance of the guide. The characteristic impedance varies directly with the width of side A for a given dimension of side B. However, side B will have to be great enough to prevent arcing within the waveguide. Side B is not critical with regard to the frequencies applied and in actual applications the dimension is made about one-half the longer dimension A.

FIELDS IN A WAVEGUIDE

An understanding of the fields present in a waveguide is necessary in order for the guides to be used effectively. Energy in a waveguide is transferred by the electromagnetic fields, while currents and voltages merely aid in forming these fields. It is important to know when a good current path is required and where the voltage will be high. Also it is important to know where the fields will exist since it is by means of these fields that energy is normally introduced into or removed from the guides. The operation of a waveguide involves two kinds of fields–the electrostatic and the electromagnetic.

Electrostatic Field

The existence of an electrostatic field indicates there is a difference in the number of electrons between two points. The simplest form of electrostatic field is the one which occurs between the two parallel plates of a capacitor. (See fig. 6-2 (A).) When the top plate of the capacitor is made positive by a battery, electrons move from the top plate and deposit themselves on the bottom plate. This sets up a stress in the dielectric between the plates. This stress is represented by arrows pointing from the more positive voltage point to the less positive, or negative voltage point. The amount of stress is indicated by either the length or the number of arrows. A long arrow represents more stress than a short arrow. In representing electrostatic fields, the number of arrows indicates the strength of the field (fig. 6-2). In the case of the capacitor, note that the arrows are evenly spaced across the area between the two plates. As the voltage across the plates is the same at all points, the electrostatic lines between the plates are evenly distributed. This set of lines forms an elec-



AQ. 36

Figure 6-2. –Electric field between capacitor plates and a full-wave section of two-wire line.

trostatic field. This field is usually called the electric field and is abbreviated the E-field. The lines of stress are called the E-lines.

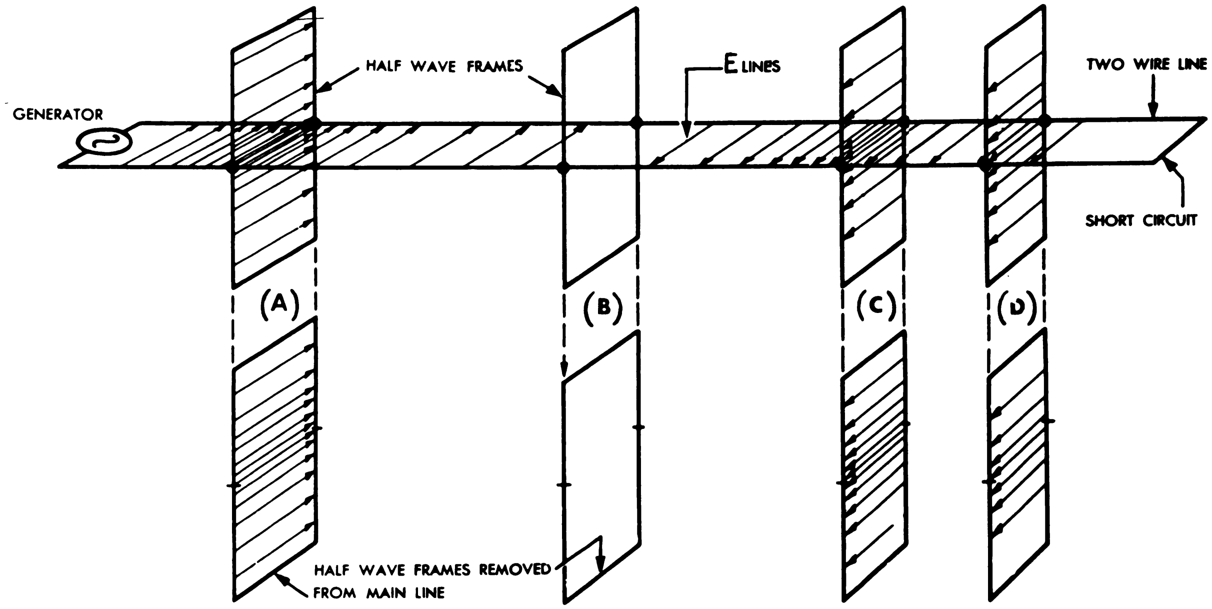
Notice in (B) of figure 6-2 that the two-wire transmission line has an instantaneous standing wave of voltage applied to it. This line is equal to one wavelength. At the same time, part of it is positive while another part is negative. The instantaneous electrostatic field (E-field) is the same at the negative and positive points, but the arrows representing each field point in opposite directions. The voltage along the line varies sinusoidally. Therefore, the density of the E-lines varies sinusoidally.

An easy way to show the development of the E-field in a waveguide is from a two-wire transmission line which has quarter-wave insulators. Figure 6-3 shows the two-wire line previously discussed with several double quarter-wave insulators, or half-wave frames used as insulators.

The E-field on the main line is the same as that in the transmission line, as illustrated in figure 6-2. The half-wave frames located at points of high voltage will have a strong E-field across them. The half-wave frames located at a voltage minimum point will have no E-field across them. Frame (A) of figure 6-3 is an example of an insulator with a strong E-field. Each frame is shown separately below the main line for a clearer view. Frame (B) is at a zero voltage point, so it will have no field on it. Frame (C) also has a strong field, but its polarity is reversed. Frame (D) has a weaker field on it because it is at a lower voltage point on the main line. The picture shown is a buildup to the three dimensional aspect of the full E-field in a waveguide.

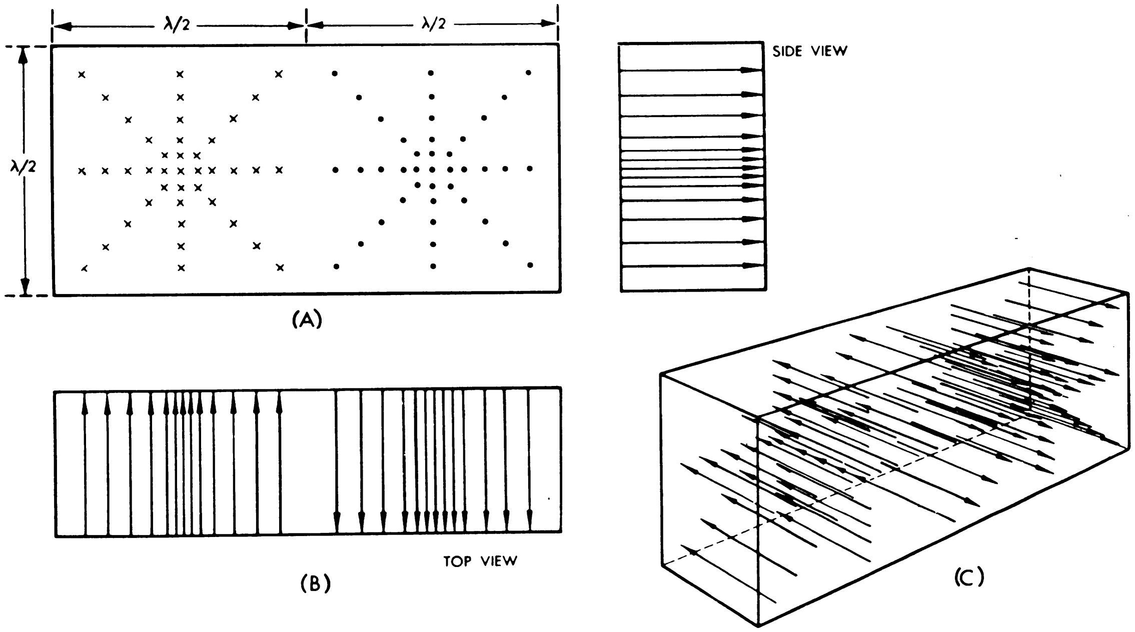
Figure 6-4 shows the E-field in an actual waveguide. This field results when an infinite number of quarter-wave sections are connected to the line to form a rectangular box. The E-field is strong at one-quarter and three-quarter distances from the shorted end, but becomes weaker at the sine rate toward the upper and lower walls and toward the ends and center. Again the phenomenon of wavelength is present, as shown in figure 6-4 (A). This is an instantaneous picture taken at the time the standing wave of voltage is at its peak. At other times, the voltage and E-field vary from zero to the peak value, reversing direction on every alternation of the applied voltage.

Certain boundary conditions must exist in order for propagation to occur in a waveguide. The principal one is that there must be no electric field tangent to the walls of the guide. This is satisfied by the E-field diminishing to zero at the top and bottom of the guide by natural RF line action; while at other places, the field is perpendicular to the walls.



AQ. 37

Figure 6-3. —Magnitude of fields on half-wave frames varies with strength of field on main line.



AQ. 38

Figure 6-4. –E-field in an actual waveguide.

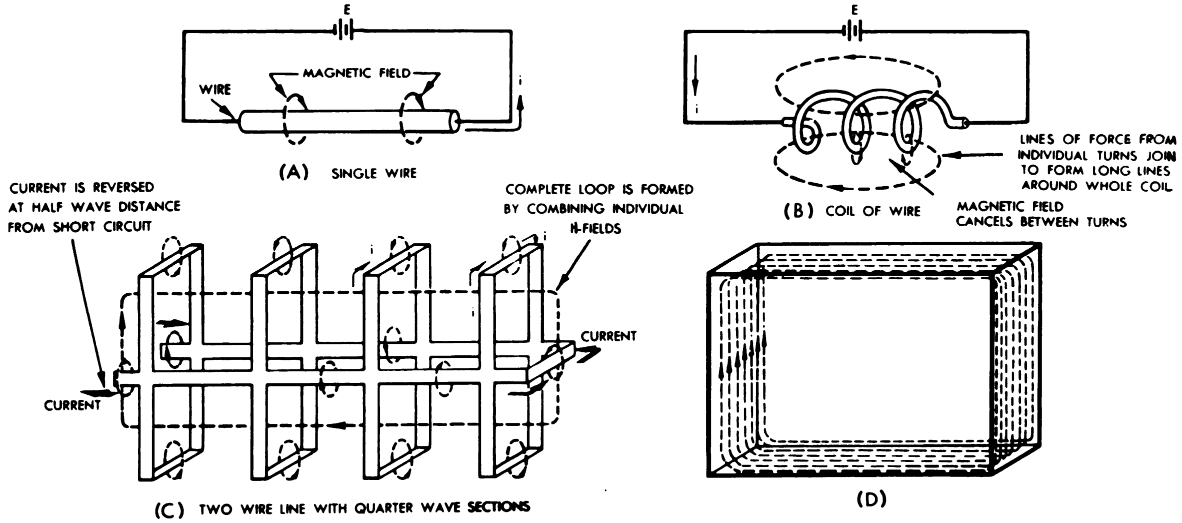
Electromagnetic Field

The second field which must always exist in a waveguide is the electromagnetic field, a term which is often shortened to "magnetic field." The magnetic lines of force which make up the magnetic field are caused by the movement of electrons in the conducting material. All the tiny magnetic forces exerted by the individual moving electrons add together and form a large force around the conductor. The presence of the force is shown by closed loops around the single wire in (A) of figure 6-5. The closed loops are formed of magnetic lines of force, or H-lines, which must be continuous, or closed, in order to exist. These lines are associated with a current; their number varies directly with the amount of current present; and the total number of lines considered collectively is called the H-field. Each H-line has a definite direction, which can be determined by use of the left-hand rule; and in the diagrams which follow, the strength of the field is indicated by the number of H-lines drawn in a given area.

Although H-lines encircle a single straight wire, they behave differently when the wire is wound into a coil. (See fig. 6-5 (B).) In a coil the individual H-lines tend to form around each turn of wire, but in doing so take opposite directions between adjacent turns. This causes cancellation and results in zero field strength between the turns. But inside and outside the coil, the directions are the same for each H-field. Therefore, the fields join and form a continuous H-line around the entire coil.

Similar action also takes place in a waveguide. In diagram (C) of figure 6-5, a two-wire line with quarter-wave sections is shown. Current flows in the main line and the quarter-wave sections. The current direction produces the individual H-lines around each conductor. When a large number of sections exist, the field cancels between the sections, but their directions are the same inside and outside the waveguide. At halfwave intervals on the main line, current will flow in opposite directions. This produces H-line loops with opposite directions. In figure 6-5 (C), current at the left end is opposite to the current on the right end. The individual loops on the main line are opposite in direction. All around the framework, they join in such a manner that the long loops shown in (D) are formed. Outside of the waveguide, the individual loops cannot join to form a continuous loop. Thus there is no magnetic field outside of a waveguide.

Figure 6-6 shows a conventional presentation of the magnetic field in a waveguide three half wavelengths long. Note that the field is

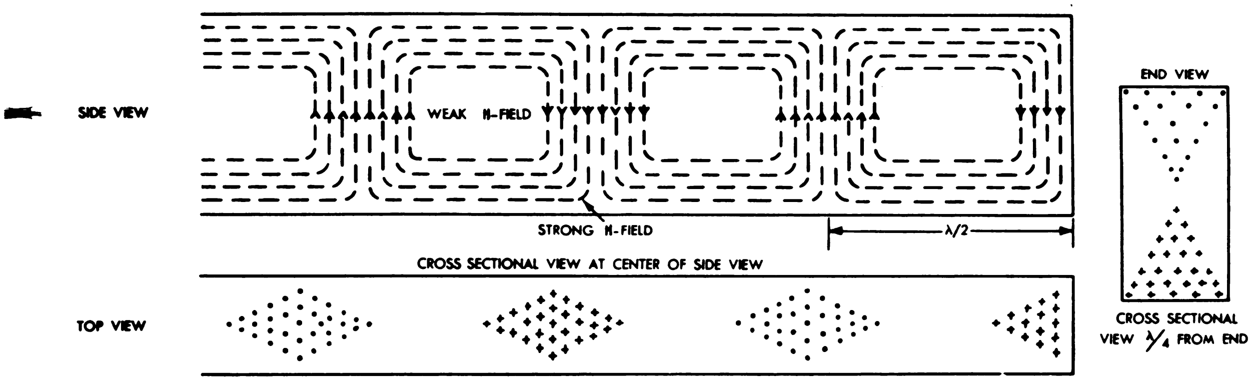

E
MAGNETIC FIELD
WIRE
i
(A) SINGLE WIRE
E
i
LINES OF FORCE FROM INDIVIDUAL TURNS JOIN TO FORM LONG LINES AROUND WHOLE COIL
(B) COIL OF WIRE
MAGNETIC FIELD CANCELS BETWEEN TURNS
CURRENT IS REVERSED AT HALF WAVE DISTANCE FROM SHORT CIRCUIT
COMPLETE LOOP IS FORMED BY COMBINING INDIVIDUAL H-FIELDS
i
CURRENT
CURRENT
(C) TWO WIRE LINE WITH QUARTER WAVE SECTIONS
(D)

AQ. 39

Figure 6-5.—Development of magnetic field or H-field in the waveguide.

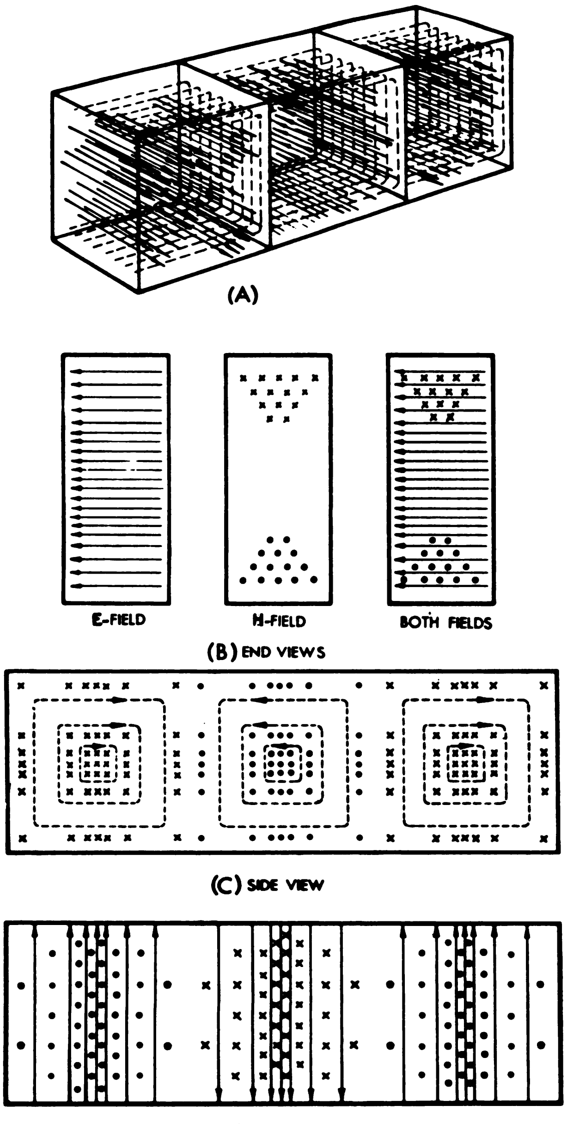
strongest at the edges of the waveguide. This is where the current is highest. The current is lowest at the center of each set of loops because there the standing wave of current is zero at all times. Figure 6-6 represents an instantaneous condition. During the peak of the other half cycle of a-c input, all field directions are reversed. An instantaneous picture of this condition would show the field reversed at half wave intervals, since the current in the long line is reversed over half-wave distances.

A second boundary condition necessary for electromagnetic fields to transfer power is satisfied by the configuration of the magnetic field. This condition requires that at the surface of the waveguide there be no perpendicular component of the magnetic field. Since all the H-lines are parallel to the surface, this condition is satisfied. Thus, energy can be transmitted by a waveguide and is carried in the electromagnetic fields within the guide. Since the electric field is zero where it is parallel to the metal surface of the guide, no part of this field can penetrate the metal. In the same way, the varying magnetic field is zero at the surface of the metal where it attempts to penetrate the walls of the guide, so that no part of the magnetic field can get outside the guide. Therefore, all of the energy in the field is wholly contained by the guide. Thus, measurements on the outside of the guide can detect neither oscillating


SIDE VIEW
WEAK H-FIELD
STRONG H-FIELD
λ/2
CROSS SECTIONAL VIEW AT CENTER OF SIDE VIEW
TOP VIEW
END VIEW
CROSS SECTIONAL VIEW λ/4 FROM END

AQ. 40

Figure 6-6.—Magnetic field in waveguide three half wavelengths long.



AQ.41

Figure 6-7.–Conventional picture of both fields in a waveguide.

electrons nor any electromagnetic fields caused by the electrical energy within the waveguide.

Electric and magnetic fields exist simultaneously in the waveguide. In fact, the H-field causes a current which in turn causes a voltage difference. This causes an E-field and it in turn causes a current which causes an H-field. This is a continuous action. One field is dependent on the other as energy is transferred continually from one field to the other.

The conventional picture of both fields in the waveguide is shown in (A) of figure 6-7. Since this illustration is rather complicated, the presence and direction of the fields are usually indicated in simpler diagrams, such as (B), (C), and (D). In these diagrams the number of E-lines in a given area indicates the strength of the electrostatic field, while the number of H-lines in any given section indicates the strength of the magnetic field in that area.

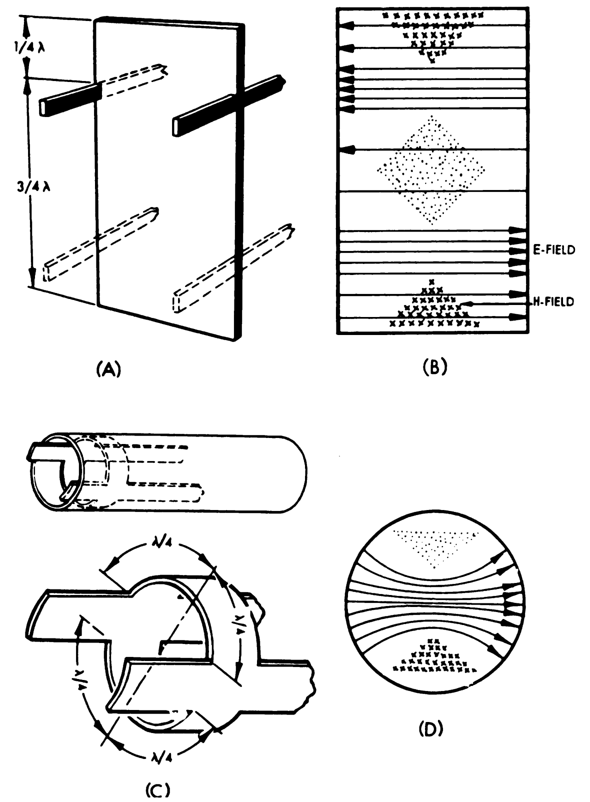
The field configuration shown in figure 6-7 represents only one of the many ways in which fields are able to exist in a waveguide. Such a field configuration is called a mode of operation. In the case of the rectangular waveguide illustrated in figure 6-7, the configuration is known as the dominant mode, because it is the easiest one to produce. Other higher modes–that is, different field configurations–may occur accidentally or may be caused deliberately in a waveguide.

An example of another field configuration is developed in (A) of figure 6-8. If the size of this waveguide is doubled over that of the waveguide shown in the previous illustration, the cross section will be a full wave rather than a half wave. The two-wire conductor can be assumed to be a quarter wave down from the top (or a quarter wave up from the bottom). The remaining distance to the bottom is three-quarters of a wave. A three-quarter wave section has the same high impedance input as the quarter-wave section. Thus the two-wire line is properly insulated and will transfer energy. The field configuration will show a full wave across the wide dimension (B).

This field configuration can be applied to a circular waveguide. The two conductors shown in (C) of figure 6-8 are assumed to be part of the waveguide wall. The remaining part of the wall forms the quarter-wave sections, each of which acts as an insulator between the two conductors. This makes it possible to transfer energy with minimum losses. The resulting field configuration, shown at (D), is the dominant mode for a waveguide with a circular cross section.

INTRODUCING FIELDS INTO A WAVEGUIDE

A waveguide does not have the two connections which are used ordinarily by RF lines. It is necessary to use special devices to put energy into a waveguide at one end and to remove it



AQ. 42

Figure 6-8. –Other field configuration in waveguides.

from the other. In a waveguide, as with many other electrical networks, reciprocity exists in any excitation system–that is, energy may be transferred either to or from the waveguide with the same efficiency.

Waveguides may be excited by three principal methods; namely, electric fields, magnetic fields, and electromagnetic fields.

Exciting With Electric Fields

When a small probe or antenna is placed in a waveguide and fed with an RF signal, current will flow in the probe and set up an electrostatic field such as shown in figure 6-9 (A). This causes the E-lines to detach themselves from the probe and to form in the waveguide. When the probe is located in the right place, a field having considerable intensity will be set up. The best place to locate the probe is in the center, parallel to the narrow dimension and one-quarter wavelength away from the shorted end of the guide, as shown in (C). Note here that the field is strongest at the quarter-wave point. This is the point of maximum coupling between the probe and the field. Of course, the probe will work equally well at any point where E-lines exist with maximum intensity. For example, a good spot to place the probe would be a three-quarter wave distance from the shorted end.

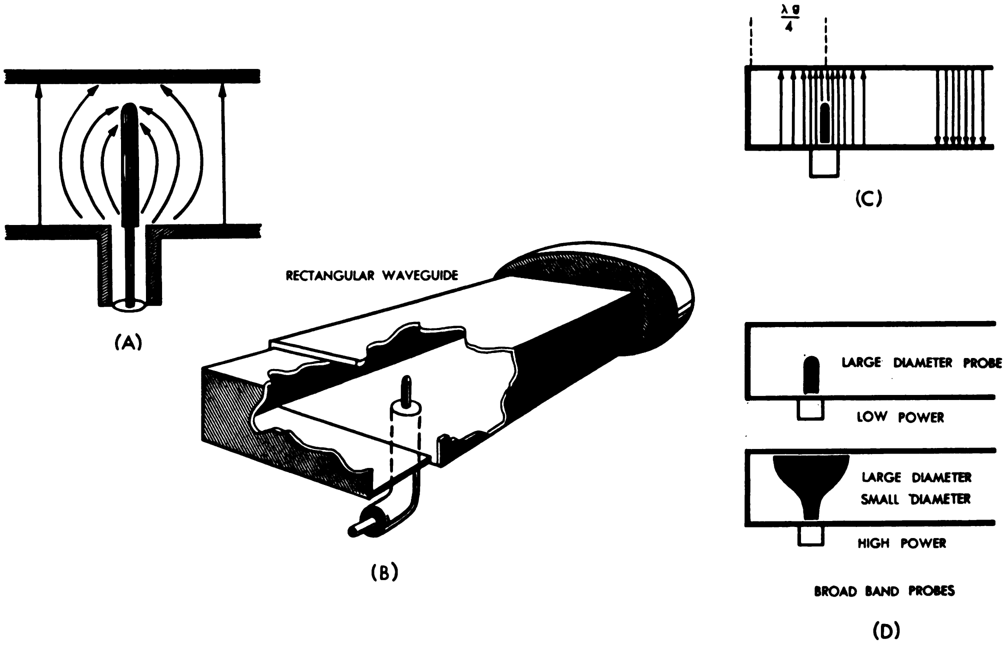
Usually, the probe is fed with a coaxial cable. In comparison with the waveguide, this cable is extremely short. This insures that the greatest benefit will be derived from the waveguide. Impedance matching between the coaxial cable and the waveguide is accomplished by varying the distance from the probe to the end of the waveguide (by moving the shorted end), and by varying the length of the probe (fig. 6-9 (B)). A mismatch will cause unwanted reflections in the waveguide.

The degree of excitation can be decreased by reducing the length of the probe, by moving it out of the center of the E-field or by shielding it. Where it is necessary to vary the degree of excitation frequently, the probe is made retractable and the end of the waveguide is fitted with a movable plunger. In airborne radar systems, the position of the probe and the endpiece is often predetermined at the factory and fixed permanently.

In pulse modulated radar systems there are wide sidebands on each side of the carrier. In order that a probe feeding system does not discriminate too sharply against frequencies which differ from the carrier frequencies, wideband probes are often used. This type of probe is large in diameter and is conical or doorknob in shape. A conical probe is capable of handling high powered signals. (See fig. 6-9 (D)). The same kind of probe is used to take energy out of the guide and deliver it to the coaxial cable.

Exciting With a Magnetic Field

Another way of exciting a waveguide is by setting up a magnetic H-field in the waveguide. This can be accomplished by placing a small loop, which carries a high current, in the waveguide. A magnetic field builds up and expands until it fills the space within the waveguide. If the frequency of the current is correct, energy will be transferred from the loop to the waveguide. A loop for transferring energy into a guide is shown in figure 6-10 (A) and (B). Notice that the loop is fed by a coaxial cable. The location of the loop for optimum coupling to the guide is at the place where the magnetic field



AQ. 43

Figure 6-9. –Exciting the waveguide with electric field.

is of greatest strength. A series of places exist where this is true. Several are shown in figure 6-10 (C). When less coupling is desired, the loop can be rotated or moved until it encircles a smaller number of lines of force.

When an excitation loop is used in aviation fire control radar equipment, its proper location is often predetermined either during construction or final tuning at the factor. In test or laboratory equipment, the loop is often made adjustable.

When a loop is introduced in a guide in which an H-field is present, a current will be induced in the loop itself. Thus, the loop may take energy out of the waveguide as well as put energy into it.

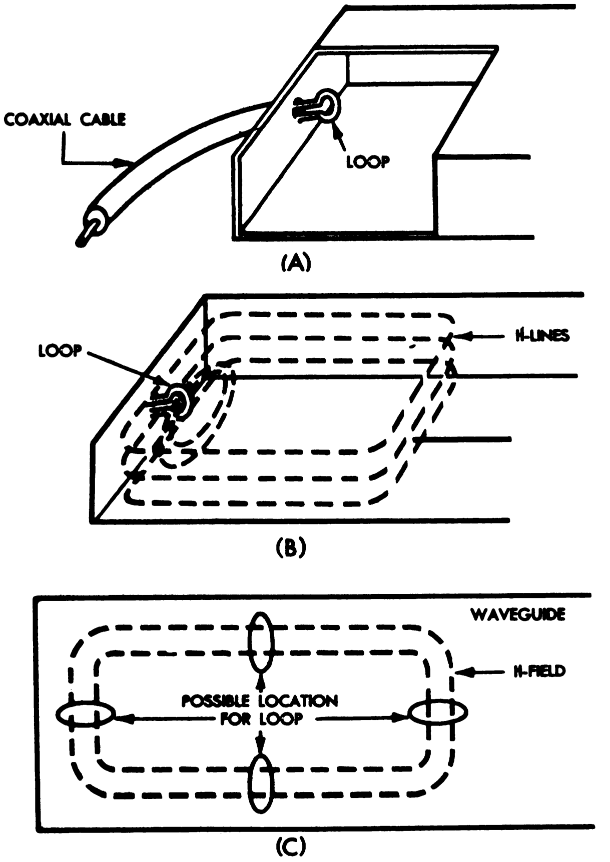
Exciting With Electromagnetic Fields

It may appear that a good way to excite the waveguide or to couple energy out of it is simply to leave the end open. However, this is not the case, for when energy leaves a guide, fields exist around the end which result in mismatch, as shown in figure 6-11 (A). In other words, reflections and standing waves would result if the end were left open. Thus, simply leaving the end open is not an efficient way of letting energy out of the waveguide.

In order for energy to move smoothly in or out of a guide, the opening of the guide may be flared like a horn, as shown in (B) of figure 6-11. This makes the guide similar to a V-type antenna. The horn in effect eliminates reflection by matching the impedance of free space to the impedance of the waveguide. When the mouth of the horn is exposed to electromagnetic fields, the fields enter and are gradually shaped to fit the waveguide. The horn is directional in characteristic. It sends or receives the greatest amount of energy in front of the opening. Flaring results in a gradual decrease in guide wavelength so that the wavelength at the mouth of the horn is nearly the same as the wavelength in space, and impedance matches wave impedance in space.

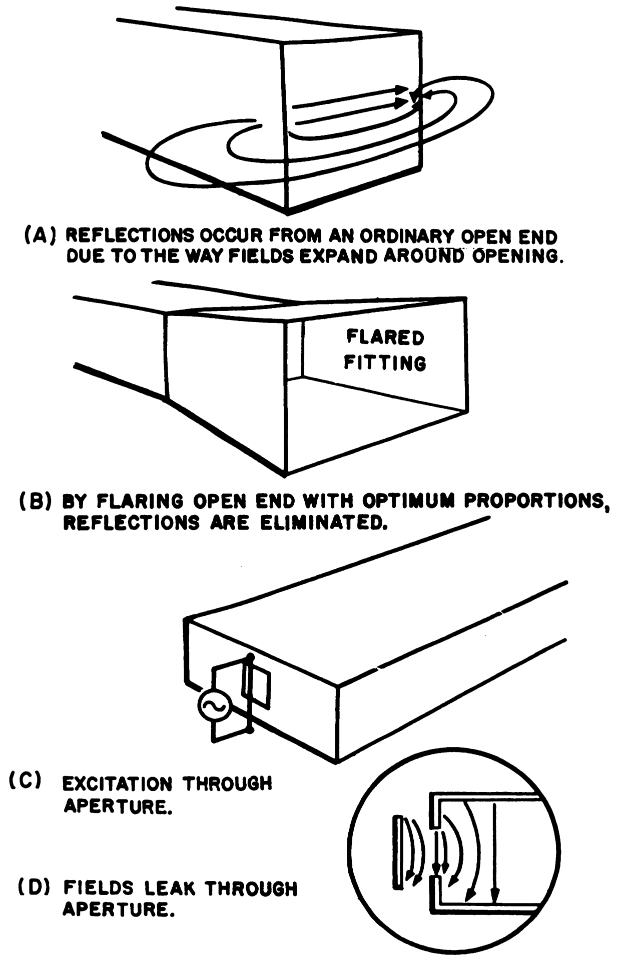
Another method for either putting energy into or removing it from a waveguide is through an aperture (sometimes called slot coupling). Aperture coupling is physically simple and is frequently found in X-band fire control radar where adjustable coupling is not required. Although coupling of this type requires no maintenance, its theory of operation is important background information.

Aperture coupling is illustrated in figure 6-11 (C) and (D). It consists of a small opening properly located in the waveguide. The



AQ. 44

Figure 6-10. –Excitation with magnetic field.


(A) REFLECTIONS OCCUR FROM AN ORDINARY OPEN END DUE TO THE WAY FIELDS EXPAND AROUND OPENING.
FLARED FITTING
(B) BY FLARING OPEN END WITH OPTIMUM PROPORTIONS, REFLECTIONS ARE ELIMINATED.
(C) EXCITATION THROUGH APERTURE.
(D) FIELDS LEAK THROUGH APERTURE.

AQ. 45

Figure 6-11. –Excitation with electromagnetic fields.

amount of coupling the aperture provides is dependent on the size, shape, and location of the opening.

Since an aperture is used with a cavity as well as a waveguide, consider its operation further. Referring to (A) of figure 6-12, the magnetic field is in the horizontal plane and the electric field (thus current flow) is perpendicular to the magnetic field as indicated. Figure 6-12 (B) shows the same wall after the aperture has been cut. A portion of this current is interrupted by the aperture. The interrupted current may be considered to flow through the impedance caused by the aperture. A part of the interrupted current is capacitively coupled across the aperture and the remaining part flows around the opening. Since the path around the opening offers inductive reactance to the applied frequency, the circuit shown in (C) of figure 6-12 may be considered an equivalent circuit for an aperture. Thus, the aperture in a waveguide may be considered, as a parallel resonant tank.

WAVEGUIDE PLUMBING

In order for energy to move from one end of a waveguide to the other without reflections, the size, shape, and dielectric material of the waveguide must be constant throughout its entire length. Any abrupt change in its size or shape results in reflections. Therefore, if no reflections are desired, any change in the direction or the size of the waveguide must be gradual. When it is necessary that the change in direction or size be abrupt, then special devices such as bends, twists, joints, or terminations, must be used.

Bends

Waveguides may be bent in several ways to avoid reflections (fig. 6-13). One is to make the bend gradual. It must have a radius of bend greater than two wavelengths in order to minimize any reflection. Some bends may be 90° bends; others may be greater or less than 90°, depending upon the requirements of the system. Still another type of bend is the sharp bend.

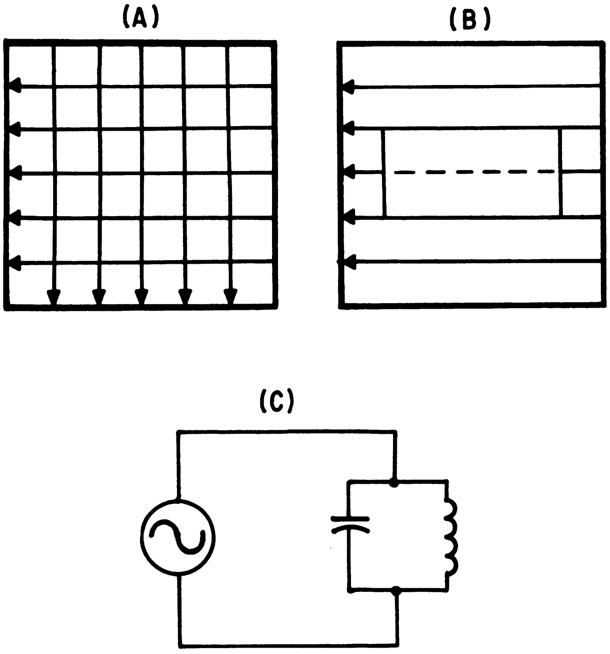


Figure 6-12.–Development of an aperture.

A bend can be made in either the narrow or wide dimension of a guide without changing the mode of operation. Normally, in sharp 90° bend, reflections will occur. To avoid this, the guide is bent twice at 45°, one-quarter wave apart. The combination of the direct reflection at one bend and the inverted reflection from the other bend will cancel and leave the fields as though no reflection had occurred.

To permit using any special bend which an installation might require, sections of waveguides are often made flexible. These sections can be bent or twisted in any desired direction. They usually consist of a spiral wound ribbon of brass. In cross section the winding is exactly the same size as the waveguide. The entire assembly is like a spiral spring in that it can be bent or twisted into any desired shape. As skin effect keeps the current at the inner surface of the waveguide, the inside surface of the flexible section, and any other section where attenuation is critical, is plated with either copper or silver. This provides for maximum current conductivity. The outside of the section is covered with rubber. This gives the section flexibility and at the same time makes it both airtight and watertight.

Rotating the Field

Sometimes it is desired to rotate the electromagnetic fields so that they are in the proper direction for matching.

This may be accomplished by twisting the waveguide (fig. 6-14). The twist should be gradual and extend over two or more wavelengths to prevent excessive reflections. Flexible sections also are used to rotate fields.

Joints

Since it is impossible to mold an entire waveguide system in a radar set into one piece, it is necessary to construct it in sections, and then to connect the sections together by joints. There are three main types of joints: the permanent, the semipermanent, and the rotating joints.

On the surface it would appear that joining two waveguide sections together would only require that the sections be the same size and fit tightly at the joint. However, irregularities at the joints set up standing waves and allow energy to escape. One kind of joint which affords a good connection between the parts of a waveguide and which has very little effect on the fields is the PERMANENT TYPE. This joint is made at the factory. When it is used, the waveguide sections are machined within a few thousandths of an inch and then welded together. The result is a hermetically sealed and mirror smooth joint.

Where it is necessary that sections be taken apart for normal maintenance and repair, it is impractical to use a permanent joint. To permit portions of the waveguide to be taken apart, they are normally connected with semipermanent joints. The most common type of semipermanent joint is the choke joint. A cross sectional view of a choke joint is shown in figure 6-15 (A). It consists of two flanges which

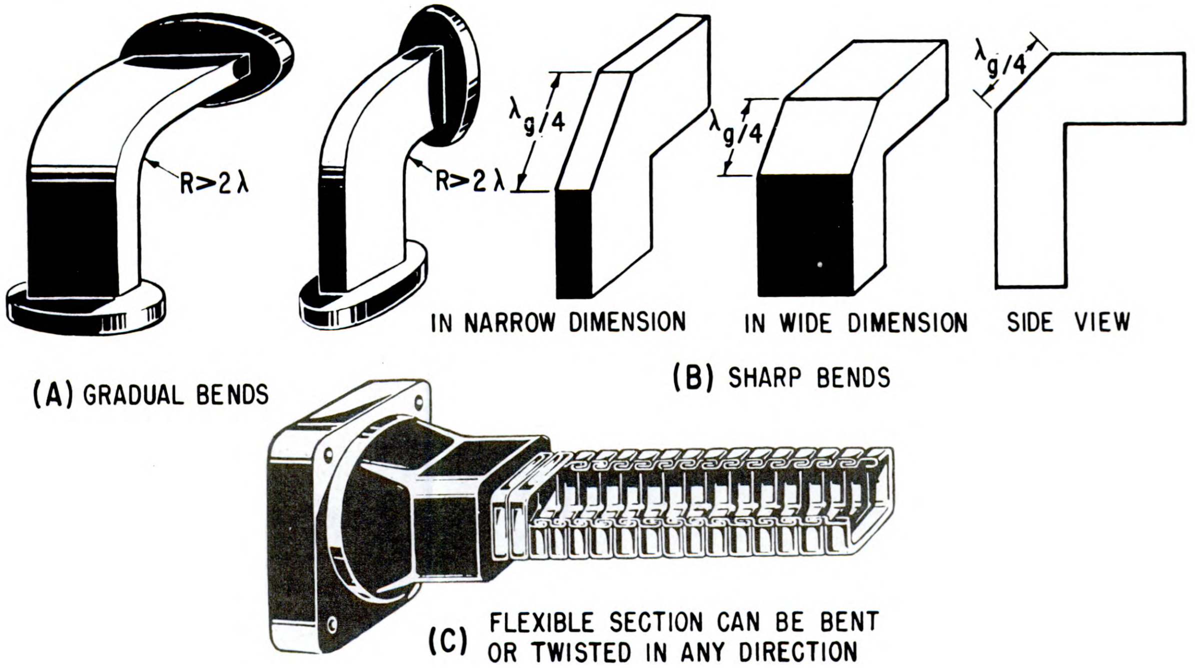


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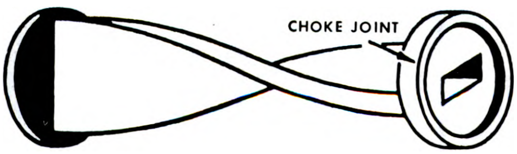
Figure 6-13.—Types of bends.



AQ.48

Figure 6-14.—Twisted section of waveguide rotates the field with minimum reflections.

are connected to the waveguide at the center. The right-hand flange is flat, and the one at the left is slotted a quarter wave deep at a distance a quarter wave from the point where the walls of the guide are joined. The quarter-wave slot is shorted at the end. The two quarter waves together become a half wave and reflect a short circuit at the place where the walls are joined together. Electrically, this creates a short circuit at the junction of the two waveguides. The two sections actually can be separated as much as one-tenth of a wavelength without excessive loss of energy at this joint. This separation allows room to seal the interior of the waveguide with a rubber gasket for pressurization. The quarter-wave distance from the walls to the slot is modified slightly to compensate for the slight reactance introduced by the short space and the open circuit from the slot to the surface of the flange.

The name CHOKE JOINT is said to come from the similarity between the action of this joint on RF fields and the action of an RF choke in a power supply lead. An RF choke keeps RF in the circuit where it belongs. Similarly, the choke joint keeps the electromagnetic fields in the waveguide where they belong. The loss introduced by the well-designed choke is less than 0.03 db, while a well-machined, unsoldered permanent joint has a loss of 0.05 db or more.

Rotating joints are usually required in an airborne radar system where the transmitter is stationary and the antenna is rotatable. A simple method of rotating part of a waveguide system is by using a mode of operation that is symmetrical about the axis (fig. 6-16). (NOTE: Operational modes are discussed in chapter 12 of Basic Electronics, NavPers 10087-B.)

This requirement is met by using a circular waveguide and a mode such as $TM_{0,1}$. In this method a choke joint may be used to separate the sections mechanically and to join them electrically. With this method the waveguide rotates, but not the field. The continuous field

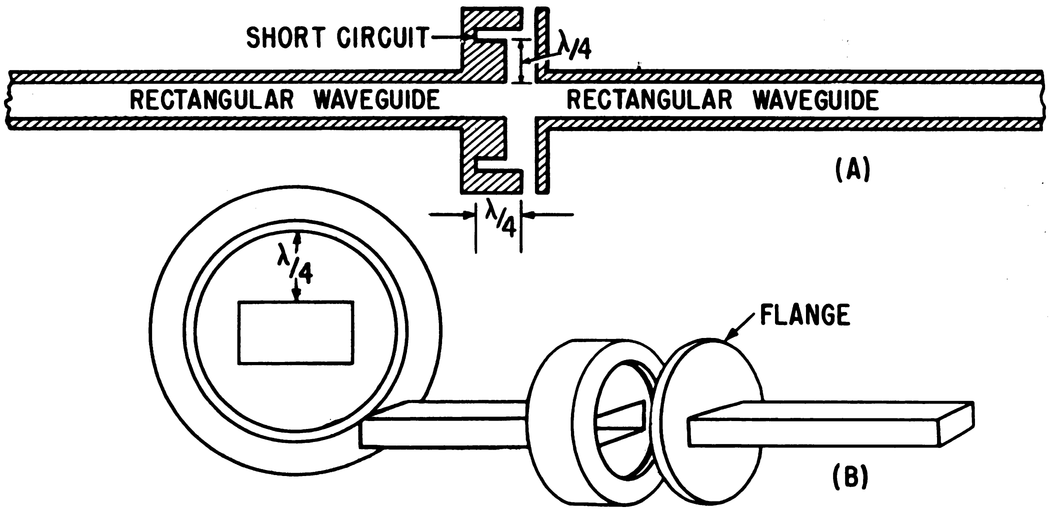
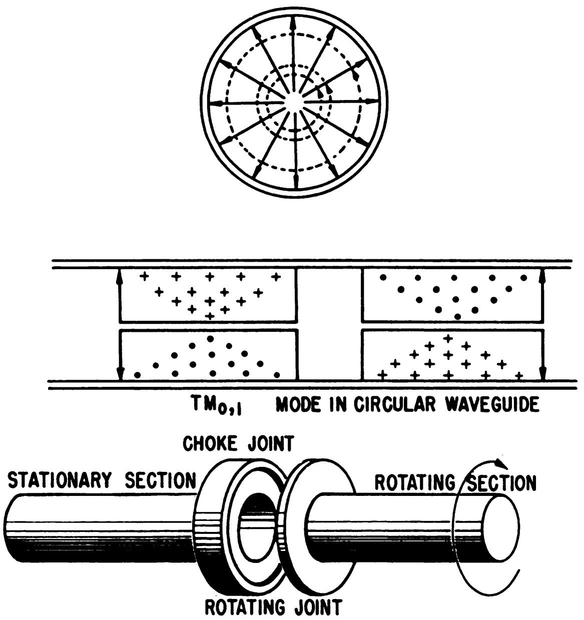


Figure 6-15.—Choke joints keep RF fields inside waveguide. AQ. 49



AQ. 50

Figure 6-16.—Rotating joint and TM$_{0,1}$ mode in circular waveguide.

produced by the fixed field minimizes reflections. Although this method is satisfactory, current airborne fire control equipment uses rectangular waveguides. This requires a different system for connecting the sections of the waveguide. For mechanical reasons the rotating joint must be circular and involves the use of a coaxial cable, as shown in figure 6-17. This cable provides axial symmetry of the fields and the circular cross section for rotation. In the rotating joint, a probe forms the end of the center conductor of the coaxial cable. The probe takes energy from one waveguide. It is then conducted through the coaxial cable and delivered through another probe to the other waveguide.

The probe in the other waveguide is one end of the center conductor. The center conductor remains stationary with respect to one waveguide and rotates with respect to the other. To make the rotating electrical connection, the outer conductor can be fitted either with sliding contacts or with the tubing by a half-wave slot. The slot which is shorted at the end reflects a short at the junction of the two outer conductors. In this method, no mechanical contact is required between the two sections of the outer conductor. The inner conductor of the coaxial cable may be supported by insulating washers, if necessary.

T-Junctions

Sometimes it is desirable to connect a section of waveguide into the side of another waveguide. This type of connection forms a T-junction. It may be connected either in the narrow side, as shown in figure 6-18 (A), or in the wide side of the waveguide, as shown in (D). When the T-junction is in the plane of an H-field of a TE$_{0,1}$ mode, it is called an H-type junction; and when the junction is in the plane of the E-lines, it is called an E-type junction.

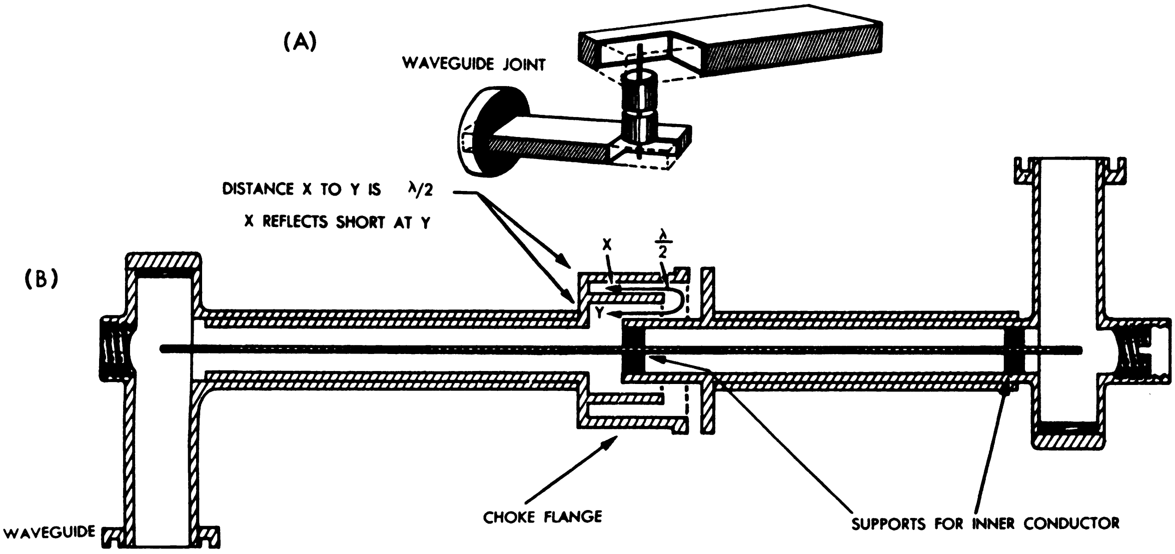


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Figure 6-17.—Rotating joint with rectangular waveguide.

The H-type junction is effectively a parallel connection with the main line. For example, when the end of the T-joint, (B) of figure 6-18, is short circuited at a distance of a half wave from the center of the waveguide, the result is the equivalent parallel circuit shown in (C). Note that (C) shows a half-wave section which is connected to a two-wire line. This section will reflect a short circuit at the line and will not allow any energy to pass. Similarly, in the waveguide itself a short circuit is reflected to the center, where the E-lines are supposed to be. Since an E-line cannot exist at a short circuit, no energy will pass that point. If the shorted end of the T-section were only a quarter wave from the center of the waveguide, an open section would be reflected there and the passage of energy would not be affected.

The E-type joint is effectively a series connection with one side of the main line ((E) of fig. 6-18). Its two-wire counterpart is shown in (F). In this case, if the section added to the waveguide is a half wave long, it will act as a short at the junction but will allow the energy to pass. The length of the added section will have to be a quarter wave in order to open the circuit at the junction and stop the ordinary flow of energy past it.

One important use of the T-joint is with the automatic transmit-receive switch (also called the TR box). In the partial transmit-receive system, illustrated in figure 6-19, an H-type T-junction is connected in the main waveguide. The switching device in this illustration is known as an anti-TR (ATR). A spark gap (TR tube) is located an odd number of quarter waves from the center of the main guide. The junction is shorted at the distance of a half wave from the center of the main waveguide. When the powerful transmitter is turned on, a spark jumps the spark gap. This causes the waveguide branch to short at that point and is inverted to an open circuit at the center. Therefore, transmitted energy can pass unhindered.

Energy received from the radar echo enters the waveguide from the other end after the transmitter is turned off. This energy is not great enough to cause a spark to jump across the spark gap. This time the shorted end of the branch reflects a short at the center of the waveguide and reflects the received energy back to another T-junction, located at the input to the receiver. Thus no energy is absorbed by the inoperative transmitter. There is a similar arrangement called a TR box placed in the waveguide leading to the receiver. It offers high impedance to the transmitted pulse but low impedance to the received echo.

In practice the actual length of the sections in a T-junction is not an exact quarter or a half wavelength because the E-fields and H-fields are not perfect around the T-junction. A distortion around the junction called FRINGE EFFECT requires some variations from exact

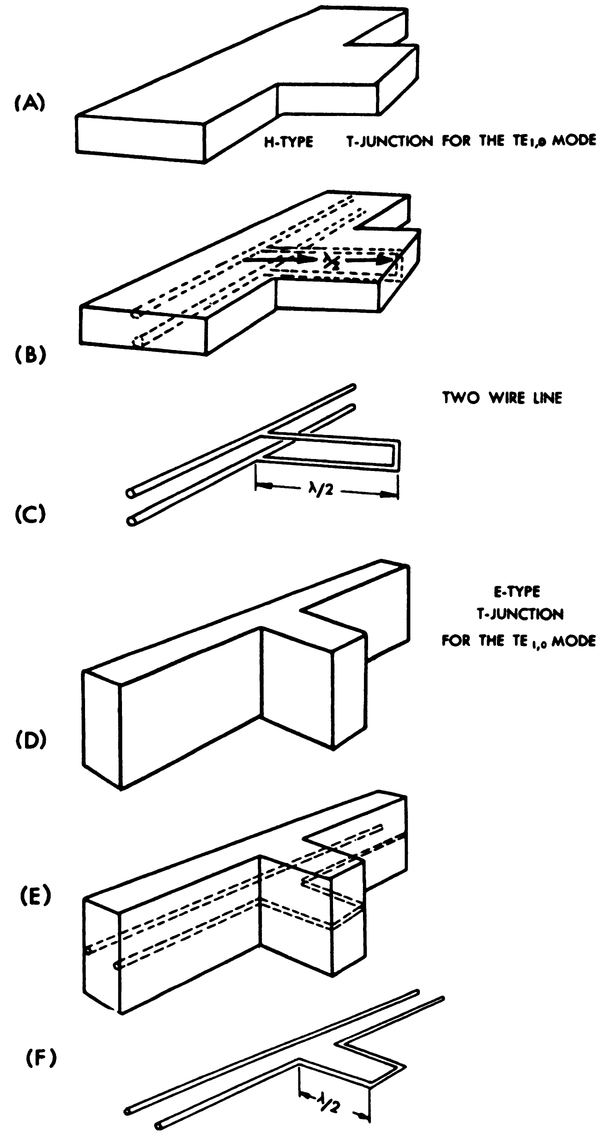

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Figure 6-18.—T-junction.

wavelengths. A more detailed coverage of TR tubes is given later in this chapter under the heading "Duplexer Systems."

MATCHING DEVICES

Some devices used in radar introduce inductance or capacitance into the circuit. Sometimes these reactances are deliberately introduced. Other times when they are present and not desired, they can be tuned out with small fins or plates in a waveguide.

Figure 6-20 shows a number of reactive plates which are deliberately used to introduce capacity or inductance in a waveguide. When these plates are employed, as shown in (A), they set up oscillations in the higher modes. Since a waveguide is too small for higher modes at the same frequency, these frequencies are not propagated, but remain in the vicinity of the plates. If the edges of the plate are vertical with respect to the plane of the H-field, the modes produced are the TM type. The effect of this on power flow is that of inductance across the two-wire line. This causes reflections and a shift in the standing wave pattern; the wider the space between the plates, the greater the inductive reactance.

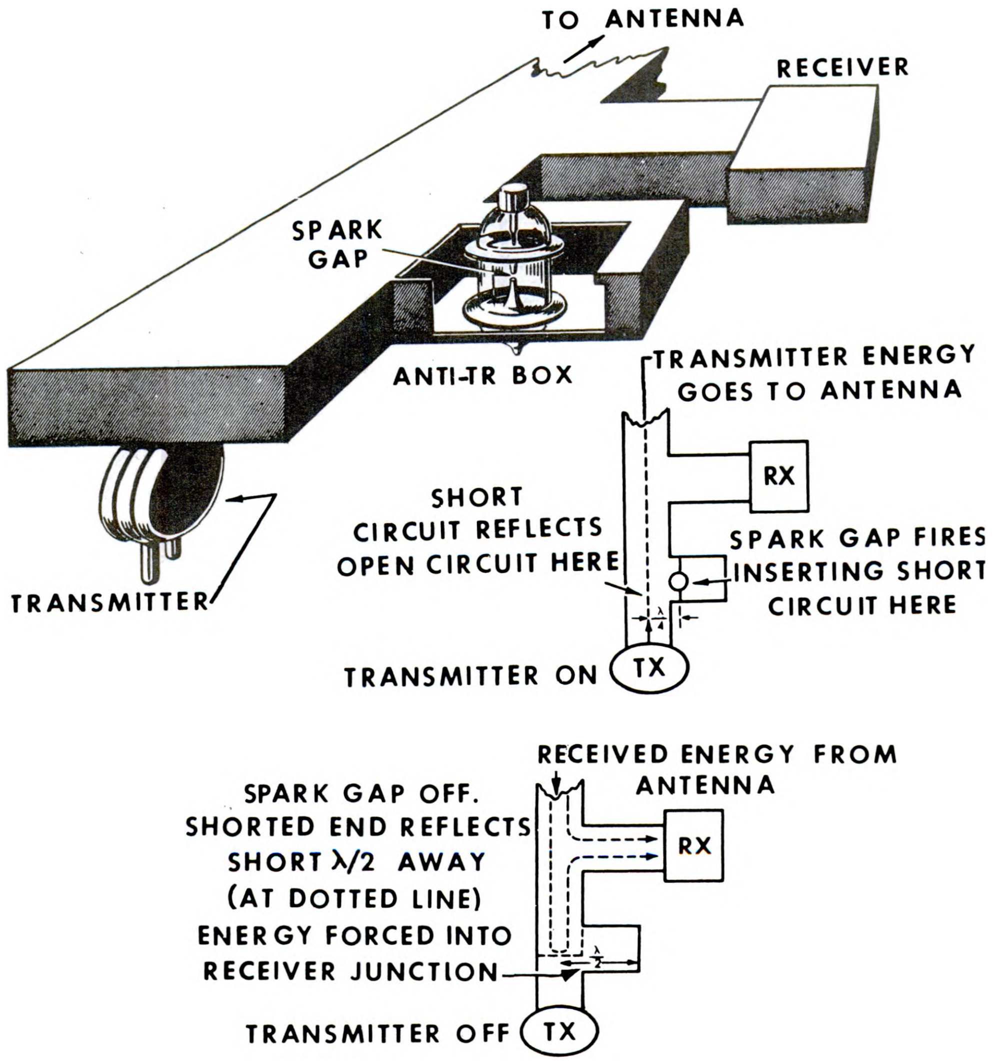
When the partitions are arranged perpendicularly to the E-field, as in figure 6-20 (B), a local E-field and the higher modes of oscillation are set up between the edges of the plates. These oscillations cannot be propagated but do change the dominant mode to a TE mode and introduce capacitive reactance. As with the TM mode, the wider the opening, the greater the reactance.

From these facts it would seem that a resonant circuit might be produced by combining both types of plates and leaving a small opening in a large guide, as shown in figure 6-20 (C). This is approximately true, provided the dimensions are correct. At resonance, a resonant circuit acts like high resistance. In this condition, a small opening would introduce a high shunt resistance and the guide would in effect have connected across it a resonant circuit, since at resonance a resonant circuit acts like a high resistance.

Terminating a Waveguide

The characteristic impedance (Z_0) of a waveguide is not as easy to define as that of a coaxial line. Nevertheless, the characteristic impedance of a waveguide is approximately equal to the ratio of the strength of the electric field to the strength of the magnetic field for energy traveling in one direction. This ratio is equivalent to the voltage to current ratio in coaxial lines on which there are no standing waves.

The lowest characteristic impedance of a circular waveguide is about 350 ohms. In a rectangular waveguide, it may be any value, depending on the dimensions of the waveguide and the frequency of the electrical energy. In


TO ANTENNA
RECEIVER
SPARK GAP
ANTI-TR BOX
TRANSMITTER
TRANSMITTER ENERGY GOES TO ANTENNA
RX
SHORT CIRCUIT REFLECTS OPEN CIRCUIT HERE
SPARK GAP FIRES INSERTING SHORT CIRCUIT HERE
λ/4
TRANSMITTER ON
TX
RECEIVED ENERGY FROM ANTENNA
SPARK GAP OFF. SHORTED END REFLECTS SHORT λ/2 AWAY (AT DOTTED LINE) ENERGY FORCED INTO RECEIVER JUNCTION
RX
λ/2
TRANSMITTER OFF
TX

AQ. 53

Figure 6-19. –T-junction as a transmit-receive switch.

this guide, it is directly proportional to the narrow dimension when the other dimension and the frequency are fixed, and may vary from approximately 0 to 465 ohms as previously discussed.

On a waveguide there is no place to connect a fixed resistor to terminate it in its characteristic impedance as there is on a coaxial cable. However, there are a number of special arrangements which accomplish the same thing. One consists of filling the end of the waveguide with a mixture of graphite and sand, as shown in figure 6-21 (A). As the fields enter the mixture, currents flow in it. These currents create heat, which is instrumental in dissipating energy. None of the energy thus dissipated as heat is reflected back into the guide. Another arrangement, figure 6-21 (B), uses a high resistance rod which is placed at the center of the E-field. The E-field (voltage) causes current to flow through the rod. The high resistance of the rod dissipates the energy as an I^2R loss.

Still another method for terminating a waveguide is to use a wedge of high resistance as shown in (C). The plane of the wedge is placed

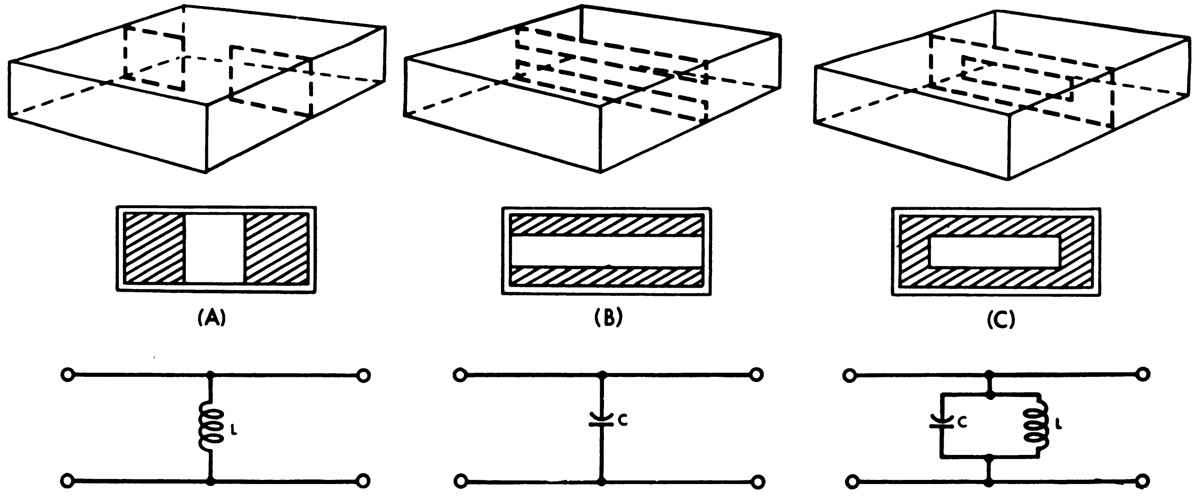


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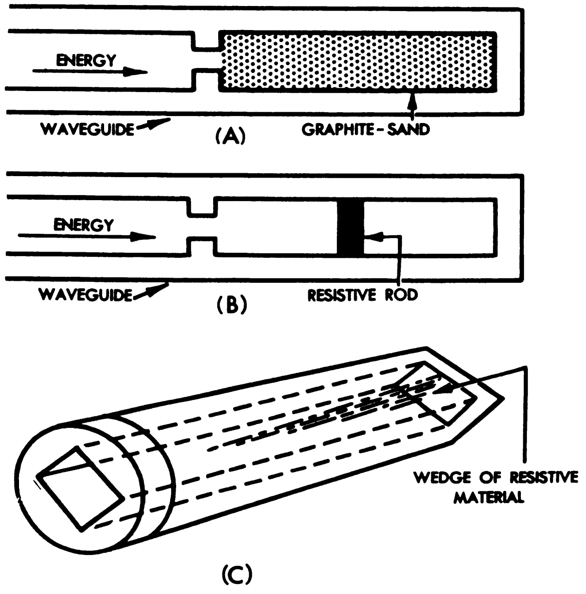
Figure 6-20. –Reactive plates in waveguide.



AQ. 55

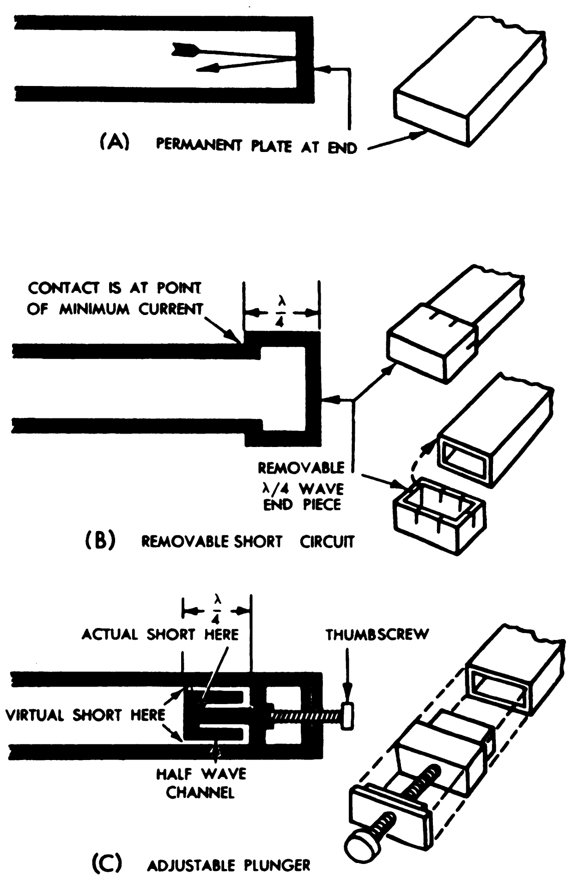
Figure 6-21. –Termination for minimum reflections.

perpendicular to the magnetic lines of force. When the H-lines cut the wedge, a voltage is induced in it. The current produced by the induced voltage on flowing through the high resistance of the wedge produces an I^2R loss. This loss is dissipated in the form of heat. This permits very little energy to reach the closed end to be reflected. These terminations are used as transmitter dummy loads for testing and in shop operation. They are generally constructed with external fins which give a larger radiation surface, thus better heat dissipation.

Each of the preceding terminations is designed to match the impedance of the guide in order to insure a minimum of reflection. On the other hand, there are many instances where it is desirable for all the energy to be reflected from the end of the waveguide. The best way to accomplish this is to weld a permanent metal plate at the end of the waveguide. (See figure 6-22 (A).)

When it is necessary that the end be removable, a removable end plate is attached to the end of the guide. For this method to be satisfactory, the contact between the guide and the end plate must be exceptionally good in order that the H-field will not be attenuated when current flows. Perfect contact is not required when the connection is made at a point of minimum current. This point is located a quarter wave from the end. When connection is made at this point, a cup is used instead of the end plate. (See fig. 6-22 (B).) This cup is a quarter wave long and large enough to fit over the end of the guide. The voltage between opposite sides of the cup opening is high but as the reflected H-field cancels the incident H-field, the resulting current is very small and reflection is at a minimum.

When the end must be adjustable, the contact must be nearly perfect. However, it is impossible to get a perfect contact. The best



AT.218

Figure 6-22.—Termination for maximum reflection.

arrangement, which is similar to the choke joint previously explained, consists of an adjustable plunger which fits into the guide as shown in figure 6-22 (C). The walls of the waveguide and the plunger form a half-wave channel. The half-wave channel is closed at the end and reflects a short circuit across the other end, where a perfect connection is supposed to exist between the wall and the plunger. The actual physical contact is made at a quarter-wave distance from the short circuit, where the current is minimum due to the standing waves. This makes it possible for the plunger to slide loosely in the guide at a point where the contact resistance to current flow is very low.

Directional Couplers

Directional couplers are devices used to couple test equipment to a waveguide and are commonly included as a permanent section of the transmission line. They are used for measuring power in the waveguide, such as radar transmitter power output. They are also used to inject a signal of known power into the waveguide to determine receiver sensitivity. Directional couplers have a fixed amount of attenuation which is generally stamped on the coupler. This type of coupling is used extensively as it contains no moving parts and injects negligible reflection into the waveguide.

A directional coupler couples energy from a wave going in one direction in a guide but not from a wave going in the other direction. There are two types of directional couplers—TWO-HOLE and ONE-HOLE.

A two-hole directional coupler is shown in figure 6-23 (A).

In figure 6-23 (B), note that a wave traveling to the right in the bottom guide has two paths into the upper guide—one from A to D and the other path B to C. However, the two paths differ in length by one-half wavelength, so that waves arriving by both paths interfere destructively, and no wave proceeds to the left in the upper guide. Also, note that waves going to the right in the upper guide are lost in the absorbing material. However, if the wave in the main guide moves to the left, then the two paths by which waves arrive at point D (path B-C-D and path B-A-D) are equal in length and a wave proceeds to the left in the upper guide, and is picked up by the test equipment probe. Thus, energy from the transmitter passing to the left

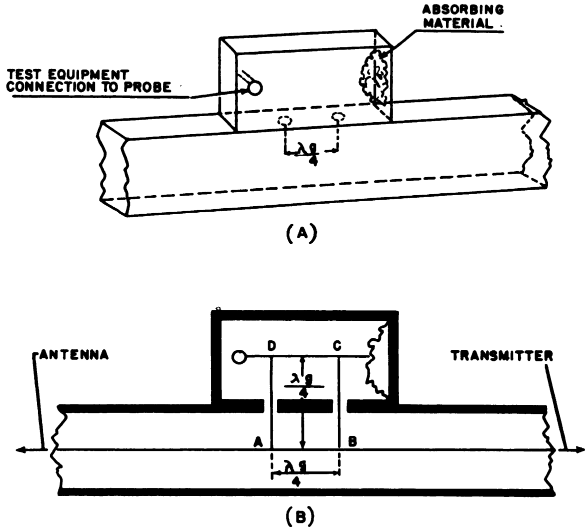


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Figure 6-23.—Two-hole directional coupler.

in the guide will reach the test equipment connection with a desirable amount of fixed attenuation, but energy picked up by the antenna which passes to the right will not reach the test equipment. A signal injected at the test equipment probe will travel toward the receiver (which is between the directional coupler and transmitter) but will not pass to the left toward the antenna.

The one-hole directional coupler is shown in figure 6-24. The coupling from the main guide to the branch is done by the electric and magnetic fields. The phase of the magnetic field is changed by the couplings so that the waves in the branch are canceled in one direction and reinforced in the other. In contrast to the two-hole coupler, the one-hole coupler transmits a wave in a direction opposite to that of the wave in the main line. The proper coupling to secure the directional characteristic depends on the orientation angle between the main guide and the branch guide and the size of the hole between the two guides.

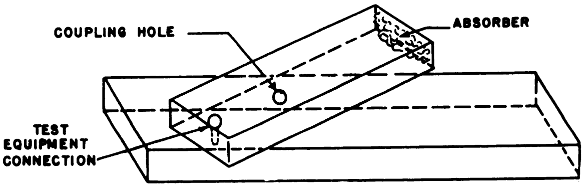

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Figure 6-24.–One-hole directional coupler.

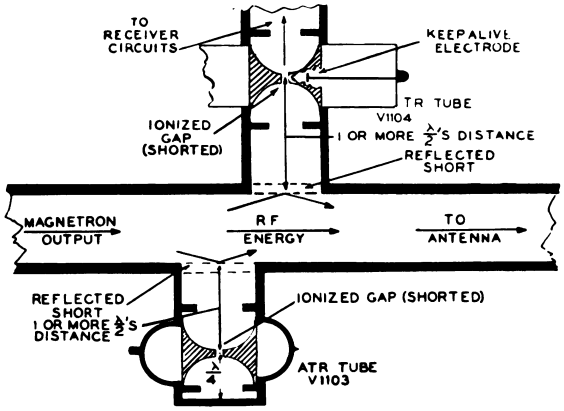
The branch guide is terminated at one end with a resistive material to absorb unwanted power, and the other end is connected to a probe for connection to the test equipment.

DUPLEXER SYSTEMS

In present day aviation fire control radar, it is desirable to use a single antenna for both transmitting and receiving. A fast acting electronic switching device is required to disconnect the receiver from the transmission line during periods of transmission and to disconnect the magnetron during periods of reception. The receiver must be disconnected in order to protect the receiver input section and crystal since the magnetron output may be several kilowatts. This function is performed by the TR device. The magnetron must be disconnected during periods of reception in order to allow all available reflected energy from the target to pass to the receiver. This function is performed by the ATR device.

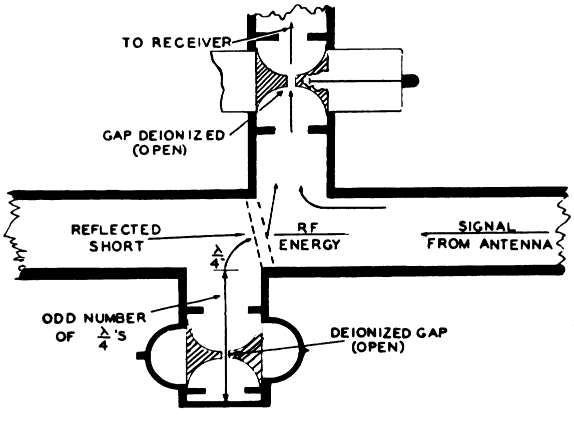
The TR and ATR devices are grouped together and referred to as a DUPLEXER. In performing the switching action the duplexer makes use of one or more gas filled tubes known as transmit-receive (TR) tubes. These tubes comprise a spark gap enclosed in a gas filled envelope. Ionization occurs during the transmitter pulse period and causes the tube to function as a short circuit or closed switch. During the reception period these tubes remain deionized because the received signals are low power; thus they appear as an open circuit.

A simplified cross section view of a waveguide system duplexer is shown in figure 6-25. The TR tube (V1104) is used to protect the crystal mixer and the receiver circuits during



TRANSMISSION OF PULSE

(A)



SIGNAL RECEPTION

(B)

AT.216

Figure 6-25.–Duplexer action in a waveguide.

transmission. When the magnetron fires, sufficient voltage is impressed on the TR tube to ionize it completely and break down the gap, producing an effective short circuit. Since the TR tube is placed a number of half wavelengths from the waveguide, a short circuit existing within the tube reflects an effective short circuit at the entrance of the receiver T-junction. This prevents the RF pulse from reaching the crystal and the receiver, but permits it to flow freely to the antenna. The operation of the duplexer during transmission is shown in figure 6-25 (A). After the pulse has passed, the tube de-ionizes and again presents a high impedance at the entrance of the receiver T-junction. This allows any reflected signals to reach the crystal mixer. Duplexer action during signal reception is shown in figure 6-25 (B).

The ATR tube (V1103) is located a number of wavelengths from the waveguide. Thus when the transmitter fires, which breaks down the gap of the ATR tube, an effective short circuit is reflected across the opening at this T-junction. This causes the wall to appear continuous to the transmitted energy; thus the energy passes unimpeded. The ATR waveguide section is so constructed that an odd number of quarter wavelengths exists between its shorted end and the opening to the waveguide. During signal reception, the ATR tube is de-ionized and causes an effective open circuit to appear at the opening of the ATR junction. This causes a reflected short across the waveguide adjacent to the TR opening, as illustrated in figure 6-25(B). The received signal is guided into the TR cavity instead of continuing to the magnetron.

Note that both TR's in this illustration are in the wide section of the waveguide. Thus they form an E-type junction whereas the application of an ATR (previously explained in this chapter under the heading T-junction) was an H-type.

CHARACTERISTICS OF TR TUBES

At atmospheric pressure approximately 30,000 volts are required to break down a spark gap of one inch. Approximately 50 volts are required to maintain ionization; this is known as running voltage. Once the voltage has been removed a lapse of approximately 10 μsec is required for de-ionization. By enclosing the spark gap in a partially evacuated envelope, the breakdown voltage will be reduced as well as the running voltage and the de-ionization time.

Figure 6-26 shows the voltage envelope that appears across the TR spark gap and the receiver input when the transmitter fires. For efficient transmitter operation it is important that the power dissipated by the TR tubes is small as compared to transmitter power. Also the TR tubes must maintain a properly matched line while they are fired. During the time that the transmitter is fired, the TR tubes must afford sufficient attenuation to prevent the power that leaks into the receiver from being so great an amplitude that it may damage the receiver crystal. To allow scope presentation of nearby targets it is necessary that the TR tubes deionize rapidly.

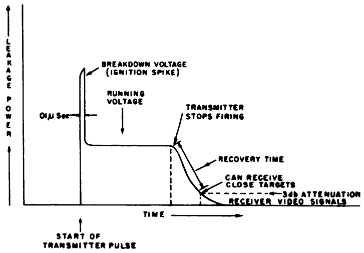


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Figure 6-26. –Voltage envelope seen across the TR spark gap when the transmitter is fired.

The amplitude and duration of the initial spike must be reduced to the extent that the receiver crystal will not be damaged. This is accomplished by providing a keep-alive voltage to the TR tubes. TR tubes that perform this function contain three electrodes, two of which provide the main gap which does the switching, and the third, called the keep-alive electrode. This keep-alive electrode is mounted close to one of the other electrodes. It is connected to a negative potential of sufficient amplitude so as to maintain a steady glow discharge near the TR gap. Within the glow discharge there is a movement of electrons between the keep-alive electrode and the spark gap electrode. When the RF pulse is applied the gap is fired more quickly because of the flow electrons. Thus, ionization time and the RF spike at the front of the pulse are reduced.

A CRYSTAL SHUTTER is frequently used as a protective device for the receiver crystal while the radar is turned off. When the radar is off, no keep-alive voltage is applied to the TR tube; thus there is the possibility that energy radiated from nearby radars may damage the crystal. A typical crystal shutter assembly may consist of a waveguide gate and a solenoid that controls the position of the gate. When the radar system is not in operation, the solenoid is not energized and the position of the gate is such that it causes a virtual short circuit across the waveguide path to the receiver input.

When the radar system is in operation, the solenoid is energized and causes the gate to move from the waveguide to a position where it will offer no interference to signals traveling to the receiver.

Protection of the receiver may be improved by installing a transformer between the waveguide and the TR tube. As a result of the step-up ratio of the transformer, the voltage across the TR tube will be greater than that across the line. This increase in voltage causes the tube to ionize faster, thus providing more receiver protection. An added benefit of the transformer action is less transmitter power loss since there is less voltage drop across the line at the T-junction of the TR tube. Resonant transformers are used for this purpose in microwave TR systems.

The cavity of the TR tube is designed to have a high Q; this necessitates careful tuning. Tuning is accomplished by means of a tuning screw which varies the separation of the main electrodes. Some equipments use a tunable ATR tube which must also be tuned to the transmitter frequency. A detuned TR will cause receiver sensitivity to drop. A means of determining if the TR is detuned is to compare the sensitivity of the receiver at the image frequency with the sensitivity of the receiver at the fundamental frequency. Before this comparison can be made it is necessary to know what this difference in sensitivity should be. This data may be obtained by making tests on a radar that is functioning in accordance with its specifications. The data obtained may be used for comparison reading.

Recovery Time

Recovery time may be described as the time required for a TR tube to de-ionize effectively. Specifically, it is the time between the end of the transmitted pulse and the time when the received signal is attenuated 3 db (half-power point). This recovery time varies from approximately 0.6 μsec to 36 μ sec, depending upon the type of gas used in the TR tube as well as the amount of transmitter power. The length of the recovery time period is determined by the length of time required for the free electrons and ions, that remain in the gas after the transmitter pulse has been removed, to recombine. This recovery period will vary depending upon the type of gas used in the TR tube.

Life of TR Tubes

The life of a TR tube is relatively short as compared with most other tubes. A major factor that shortens the life of these tubes is the gradual loss of gas pressure. This is the result of the gas being absorbed by tube electrodes. Another reason for the short life of the tubes is that molecules of gas become embedded in the electrodes; this is caused by glow and keep-alive discharge. One means of lengthening the life of these tubes is to maintain the keep-alive current within designed limits. Some equipments provide test points for making current checks. A reading lower than the normal minimum current will most likely be an indication that the TR tube is not operating at proper efficiency.

The most general indications of defective TR tubes are as follows:

1. Receiver recovery time will increase.
2. Receiver sensitivity will decrease.
3. Receiver crystals will become defective. (This may be detected by a rapid increase in crystal back current.)

Some radars use the same type of tube for TR and ATR operation. In some cases a tube that will not operate as a TR may be used satisfactorily as an ATR; thus for emergency operation the tubes may be interchanged.

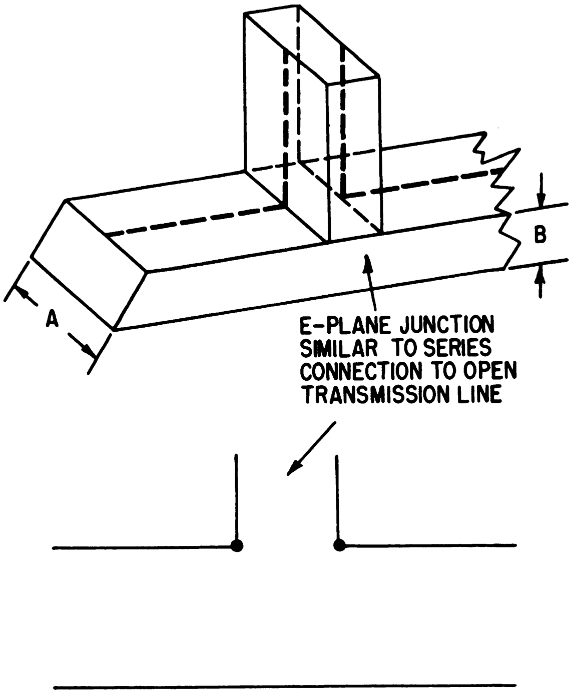
RING DUPLEXER

The hybrid ring is a type of duplexer somewhat different from those already discussed. It is capable of performing the functions of the duplexer previously discussed. In addition, it is capable of handling high power with a minimum of impedance mismatch.

The ring duplexer is a coupling device which routes the RF energy from the magnetron to the antenna, and the received signals (echoes) from the antenna to the receiver. It is a circular waveguide path to which connections are made at four critically spaced E-plane waveguide junctions. An E-plane (series) junction is one where branch arms join the waveguide at right angles across a wide side (A dimension) as illustrated in figure 6-27.

This type of junction is similar to a series connection to an open two-wire transmission line. Figure 6-28 shows the electric fields in successive wavefront positions for an analysis of an E-plane junction.

Signals arriving at the junction from the branch waveguide (fig. 6-28 (A)) divide and are


A
B
E-PLANE JUNCTION SIMILAR TO SERIES CONNECTION TO OPEN TRANSMISSION LINE

AQ. 59

Figure 6-27. –E-plane junction.

propagated down both of the inline arms, the two signals leaving the junction 180° out of phase. In-phase signals arriving at the junction from the inline arms (fig. 6-28 (B)) combine in the branch waveguide 180° out of phase and, if equal, cancel each other. Signals 180° out of phase arriving at the junction from the inline arms (fig. 6-28 (C)) combine in the branch waveguide in phase and add.

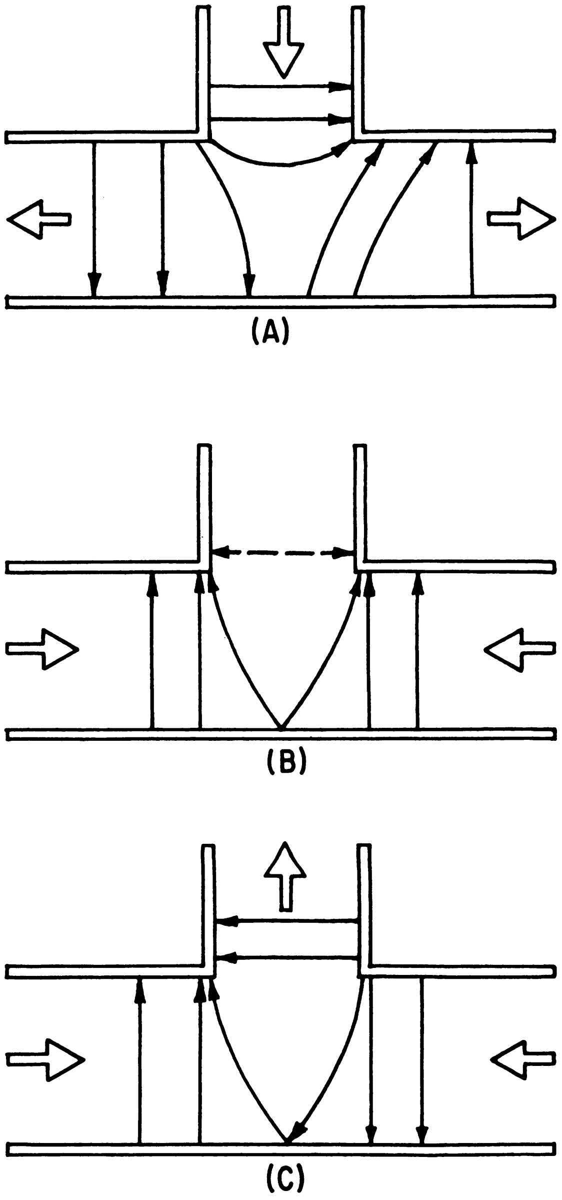


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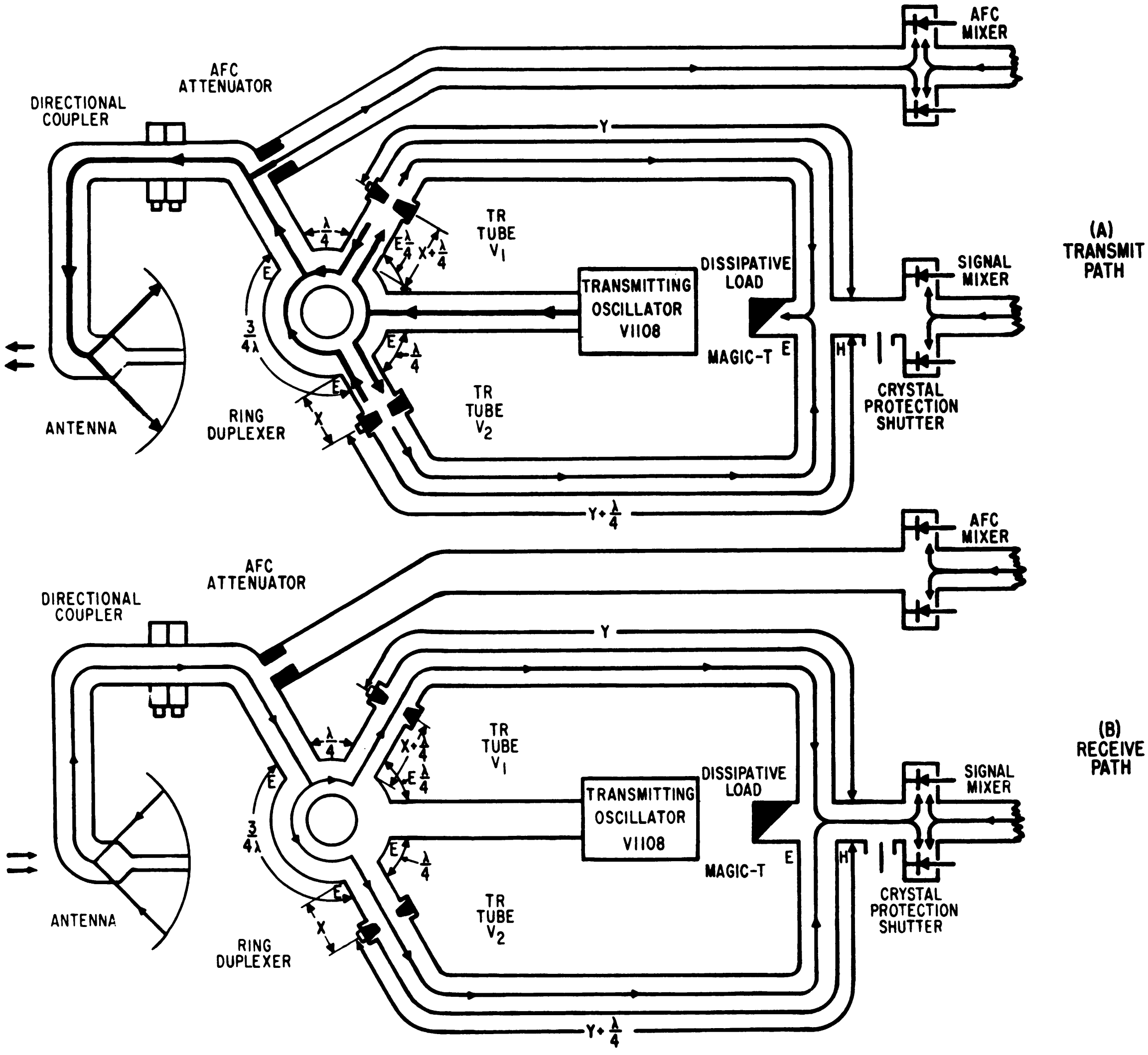
Figure 6-28. –Electrical properties of waveguide junctions.

The total length of the ring duplexer illustrated in figure 6-29 is one and one-half wavelengths; the branches are spaced one-fourth wavelength apart. The RF signal from the magnetron oscillator enters the hybrid ring duplexer and divides as illustrated in figure 6-29 (A). The two out of phase signals start in opposite directions around the ring. The signals enter the two arms of the duplexer leading to TR tubes V1 and V2. The TR tubes ionize, short circuiting the paths as in the duplexer assemblies previously discussed. Most of the energy in the signals is reflected back toward the ring duplexer. The weak signals leaking past the TR tubes, illustrated by the light lines in figure 6-29 (A), travel equal distances and arrive at the magic T-junction 180° out of phase. These signals thus enter the E-plane junction and are absorbed by the dissipative load. Transmitter energy does not enter the H-plane junction leading toward the signal mixer since out of phase signals cancel at this type of junction. The reflected energy from the TR tubes proceeds around the duplexer to the arm which is connected to the antenna. TR tube V1 is one-quarter wavelength further from the



AQ. 61

Figure 6-29. –Ring duplexer (A) and (B).

ring duplexer than TR tube V2; the energy reflected from this tube thus travels one-half wavelength farther in the TR-tube arm. This signal travels one-half wavelength in the ring duplexer while the signal reflected from V2 travels one wavelength in the duplexer.

The two-branched transmission signals thus have traveled equal distances when they reach the antenna junction and, since they left the magnetron arm out of phase, they arrive at the antenna junction out of phase. The antenna junction is also an E-plane junction; the two signals thus add and pass out through the transmitter arm. A greatly attenuated sample of the transmitted signal is taken from the antenna arm of the ring duplexer and conducted by waveguide to the AFC (automatic frequency control) mixer of the receiver section of the system.

The receive cycle of operation of a ring duplexer is illustrated in figure 6-29 (B). The received signals from the antenna leave the antenna arm of the hybrid ring 180° out of phase. The distance traveled by the received signal reaching the magic-T junction through the arm of de-ionized TR tube V2 is one-half wavelength greater than that through the arm of V1. Therefore, received signals combining at the magic-T junction are in phase and enter the H-plane junction leading to the signal mixer.

When the power is off or when the system is in standby condition, a protective shutter is used to slide in the waveguide by relay action to protect the crystal mixers from radiation of nearby radar sets. The directional coupler illustrated provides the same purposes as discussed on other duplexer systems.

Another advantage of the ring type duplexer is that no ATR device is required as with the previously discussed duplexers.

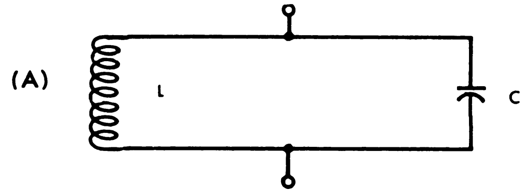
This advantage can be explained through the examination of the basic properties of hybrid junctions. If each of the side arms of the junction are terminated in the characteristic resistance of the arm, then the input impedance at the junction will be equal to the terminating resistance. This will allow for matching pairs of entries in such a manner that no power will be exchanged between entries of pairs. The ring duplexer is balanced in pairs such that the arm from the antenna and the arm from the transmitter are matched, and the two arms containing the TR tubes are also matched. When the input to the ring is from the antenna arm, as it is during receive time, the two voltage waveforms at the transmitter arm combine 180° out of phase. Thus, the output voltage is zero so no power is delivered at the entry to the transmitter, and the power is divided equally between the loads at the arms containing the TR tubes.

CAVITY RESONATORS

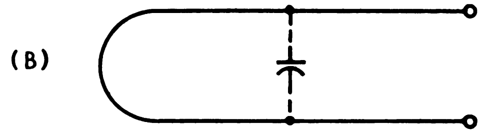
In radio work the conventional low frequency resonant circuit consists of a coil and capacitor connected either in series or in parallel as in figure 6-30 (A). To increase the resonant frequency, it is necessary to decrease either the capacitance or the inductance or both. However, a frequency is reached where the inductance is a half-turn coil and where the capacitance consists only of the stray capacitance in the coil. At extremely high frequencies this resonant circuit would consist of a coil about one inch long and a quarter of an inch across.

In this circuit the current handling capacity and breakdown voltage for the spacing would be low.

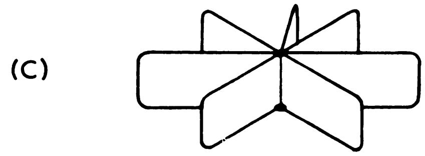
The current carrying ability of a resonant circuit may be increased by adding half-turn loops in parallel. This does not change the resonant frequency appreciably because it adds capacitance in parallel (which lowers the frequency) and inductance in parallel (which increases the frequency). As the effects of each cancel, the frequency remains about the same.



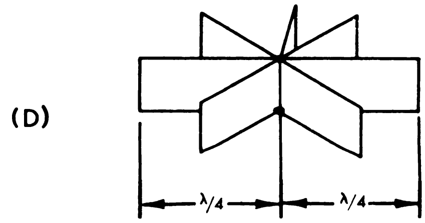
CONVENTIONAL LOW FREQUENCY CIRCUIT



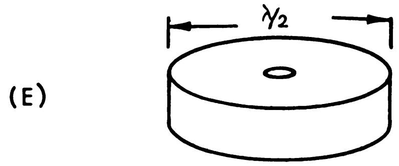
COIL-CONDENSER COMBINATION REDUCED FOR HIGHEST RESONANT FREQUENCY



HALF TURN LOOP IN PARALLEL



QUARTER WAVE SECTIONS



CLOSED METAL CONTAINER

AQ. 62

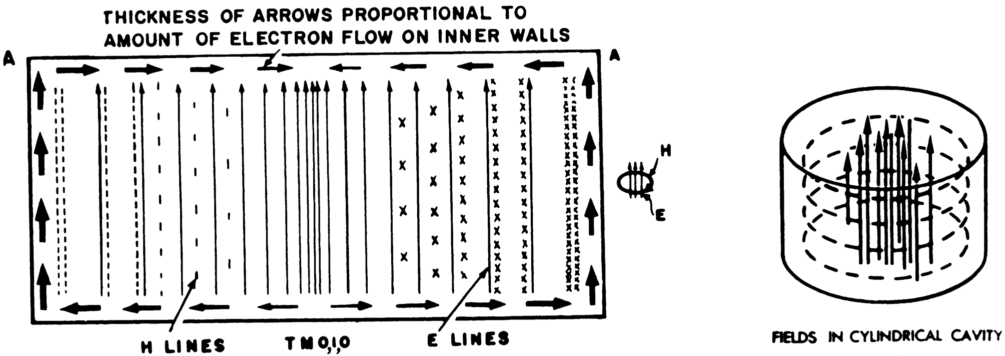
Figure 6-30. –Development of cavity from quarter-wave sections.

In figure 6-30 (C), several half-turn loops are added in parallel. Several quarter-wave Lecher lines are shown in parallel in figure 6-30 (D). These lines are resonant when they are near a quarter wavelength. When more and more loops are added in parallel, the assembly eventually becomes a closed resonant box as shown in (E) which is a quarter wave in radius or, in other words, a half wave in diamater. This box is called a RESONANT CAVITY.

A resonant cavity displays the same resonant characteristics as a tuned circuit composed of a coil and capacitor. In it there are a large number of current paths. This means that the resistance of the box to current flow is extremely low and that the Q of the resonant circuit is very high. While it is difficult to attain a Q of several hundred in a coil of wire, it is fairly easy to construct a resonant cavity with a Q of many thousand. Although a cavity is as efficient at low frequencies as at high frequencies, the large size required at low frequencies prohibits its use at those frequencies. For example, at 1 MHz a resonant cavity would be a cylinder about 500 feet in diamater. When the frequency is in the vicinity of 10, 000 MHz, the diameter of the cavity is only 0. 6 inch. This makes the cavity smaller than a conventional tuned circuit. Therefore, equipment which operates at a frequency of approximately 3, 000 MHz or above employs resonant cavities extensively.

FIELDS IN A CAVITY

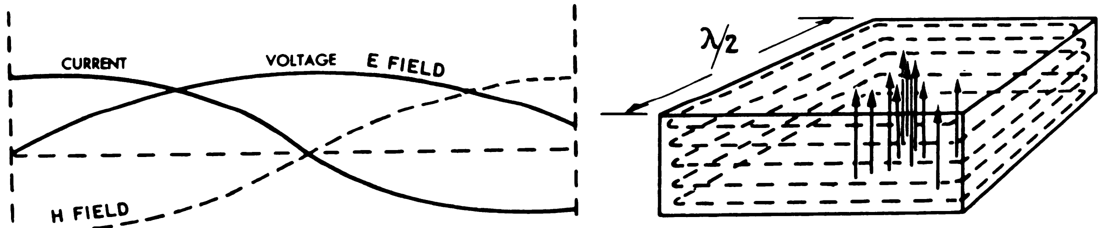
A resonant cavity may be compared to a waveguide, since its operation is best described in terms of the fields rather than in terms of the currents and voltages present. As in waveguides, the different field configurations in cavities are called MODES. The dominant mode of the cylindrical cavity is shown in figure 6-31. Note that the voltage is represented by E-lines between the top and the bottom of the cavity in figure 6-31 (A). Due to skin effect, the current flows in a thin layer on the surface of the cavity. The strength of the current is indicated by arrows of various lengths. The magnetic field is strong where the current is high. The strongest H-field is at the vertical walls of the cylinder and diminishes toward the center where the current is zero. This is due to the standing waves on the quarter-wave section. The E-field is maximum at the center and decreases to zero at the edge, where the vertical wall is a short circuit to the voltage. The curves of E-field and H-field density are shown in figure 6-31 (B); two types of cavities with their fields represented are shown in (C) and (D).


THICKNESS OF ARROWS PROPORTIONAL TO AMOUNT OF ELECTRON FLOW ON INNER WALLS
A
A
H
E
H LINES
TM0,1,0
E LINES

(A)

FIELDS IN CYLINDRICAL CAVITY

(C)



VOLTAGE AND CURRENT DISTRIBUTION ACROSS WIDTH

(B)

SQUARE CAVITY OR HALF WAVE LENGTH SECTION OF WAVEGUIDE

(D)

AQ. 63

Figure 6-31. –Voltages, currents, and associated fields for simple modes in a cavity resonator.

The modes in a cavity are identified by the same numbering system used with waveguides, except that a third subscript is used to indicate the number of patterns of the transverse field along the axis of the cavity (perpendicular to the transverse field). For example, the cylindrical cavity shown in (C) of figure 6-31 is a form of circular waveguide. The axis is the center of the circle. The transverse field is the magnetic field. Therefore, it is TM (transverse magnetic). Around the circumference there is a constant magnetic field. (The H-lines are parallel to the circumference.) Therefore, the first subscript is zero. The distance across the diameter is one-half wave. Thus, the second subscript is one. Through the center, along the axis, the H-field strength is a constant zero. This makes the third subscript zero. Therefore, the complete description of the mode is $TM_{0,1,0}$.

When a section of waveguide which is one-half wave long is closed on both ends in the form of a rectangular cavity, as shown in figure 6-31 (D), standing waves are set up and resonance occurs. The simple mode in this cavity is the same as the dominant mode of a rectangular waveguide; that is, it is $TE_{0,1}$. The third subscript of the mode, which is determined by the plane of the E-field, is one. Thus the complete description of the simple mode in the rectangular cavity in (D) is $TE_{0,1,1}$ (transverse electric).

Cavities may have various physical shapes, for any chamber enclosed in conducting walls resonates at several frequencies and produces a number of modes. Figure 6-32 shows several types of cavities. (Note the large approximate Q values indicated in some cases). Of those shown the cylinder type cavity is useful in wavemeters or in frequency measuring devices. The cylindrical ring type is used in superhigh frequency oscillators as the frequency determining element. The section of waveguide which is shown diagrammatically in figure 6-32 is used in some radar systems as a mixing chamber for combining signals from two sources.

EXCITING THE CAVITY

Energy may be inserted or removed from a cavity in the same ways in which it may be inserted or removed from a waveguide. These methods are probe coupling, loop couplings, and aperture or slot coupling. The probe method, illustrated in (A) of figure 6-33, is equivalent to capactive coupling and is accomplished by inserting a probe into the cavity at a point of maximum E-field strength.

Loop coupling, illustrated in figure 6-33 (B), is a form of magnetic or current coupling. The loop is located at a point of maximum H-lines. It should be noted that the loop is perpendicular to the tangent of the H-lines.

Aperture coupling (fig. 6-33 (C)), which may be used between two cavities or between a cavity and a waveguide, employs an aperture or window, cut in a wall that is common to the two cavities or to the cavity and waveguide. Coupling results from the penetration of the electric and magnetic fields through the opening.

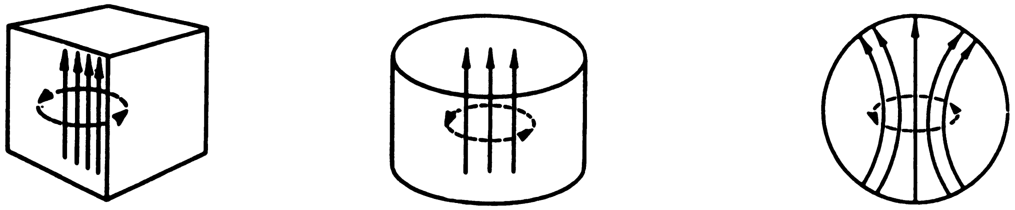
An additional means of exciting a reentrant type of resonant cavity not found in waveguides is illustrated in (D) of figure 6-33. The cylindrical ring type cavity receives energy from clouds of electrons which are virtually shot through holes in the center of the perforated plates. It may be said that the approaching cloud of electrons makes the first perforated plate positive by repelling the electrons away from it. This current starts an H-field. As the cloud of electrons approaches the second perforated plate, the process is reversed.

VARYING THE RESONANT FREQUENCY OF THE CAVITY

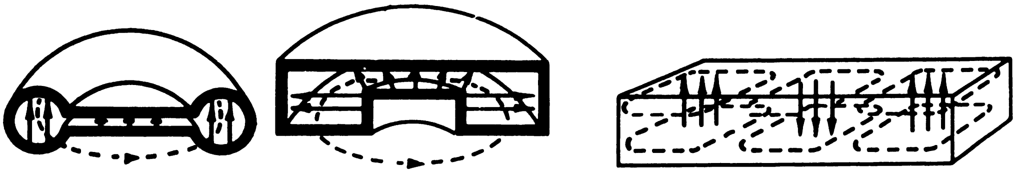
Three methods for setting the resonant frequency in a cavity are shown in figure 6-34. One method uses a cylindrical cavity with an adjustable disk. When $TE_{0,1,1}$ mode is used, the size of the cylinder may be changed along the axis to change the resonant frequency; the smaller the volume of the cavity, the higher the resonant frequency. The movement of the disk may be calibrated in terms of frequency. Usually in the case of high frequency equipment, a micrometer scale is used to indicate the position of the disk, and a calibration chart is used to determine the frequency.

A second method for varying the frequency employs threaded plugs which are inserted in the side of the cavity. The plug reduces the strength of the magnetic field in the cavity in a manner similar to reducing the inductance of the tuned circuit. The deeper the plug extends into the cavity, the higher the frequency.

In a third method, the interior of the cavity, which is part of the interior of a vacuum tube, is sealed and evacuated. In this method a frequency change occurs whenever the top and bottom of the cavity are moved away from (or



CUBE (Q = 28,000) CYLINDER (Q = 31,000) SPHERE (Q = 26,000)



DOUGHNUT-SHAPED CYLINDRICAL RING (Q = 26,000) SECTION OF WAVEGUIDE

AQ. 64

Figure 6-32. –Several types of cavities.

toward) each other. This is accomplished by turning a screw. (See fig. 6-34.) As the distance varies, the capacity between the top and bottom of the cavity is changed. There is also a slight change in volume. As the change in capacity is the chief result of the change in the distance between the plates, the resonant frequency is directly proportional to the distance from the top to the bottom.

Another way of changing the frequency is by changing the method of exciting the circuit. This can be done by tuning the exciting loop either capacitively or inductively. This can occur either accidentally due to improperly tuned circuits or deliberately as a means of tuning the cavity.

MICROWAVE FERRITES

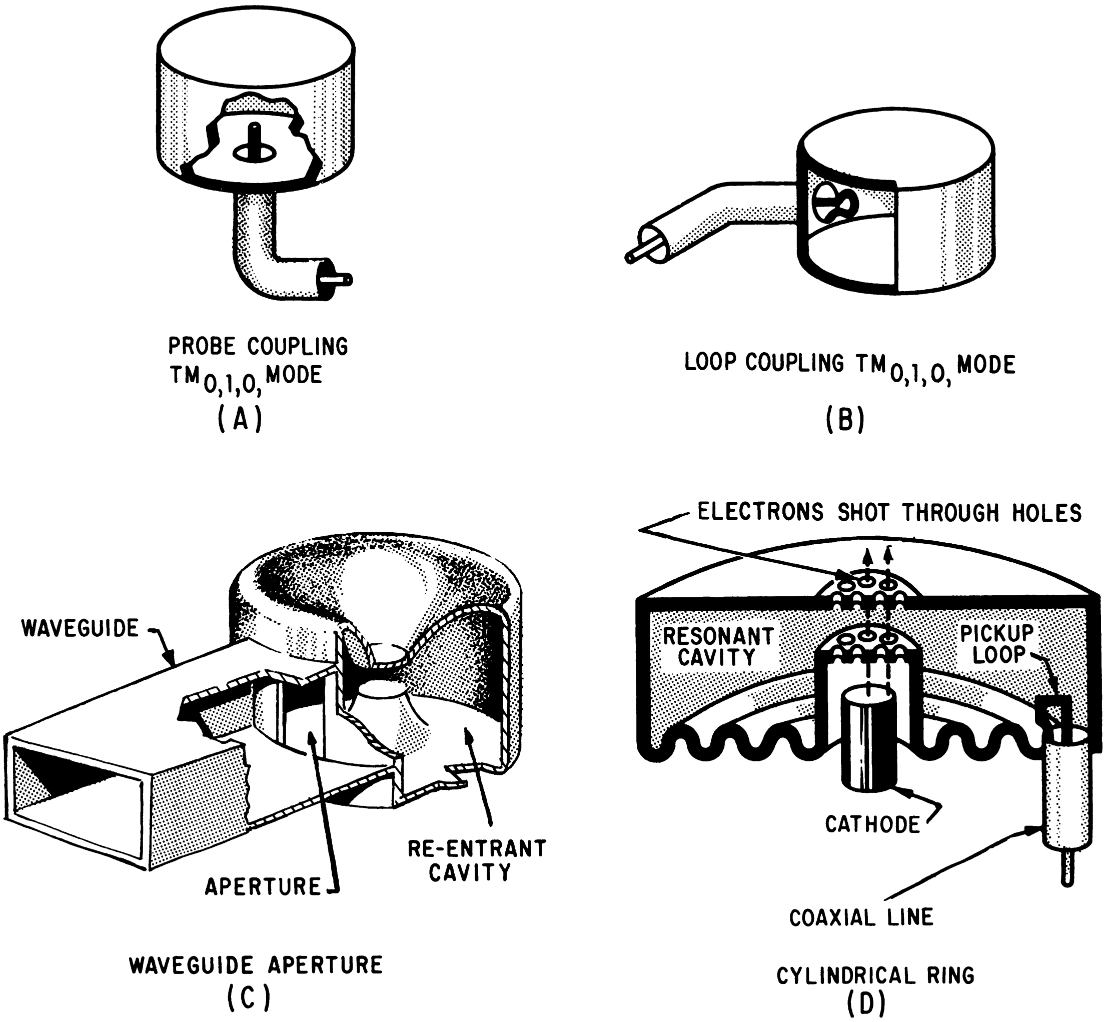
Ferrites are unique because they have useful magnetic properties and are also insulators. RF fields can penetrate ferrite; this is not possible in conducting magnetic substances.

The more common ferromagnetic substances–iron, nickel, cobalt, and their alloys–are good electrical conductors; they cannot be used as magnetic materials at the higher frequencies because of eddy current losses. The ferrites are not subject to eddy currents, and even though their magnetic susceptibility is much lower than that of the ordinary ferromagnetic substances, they can be and are used extensively at the higher frequencies. Ferrites with a wide range of magnetic and electrical properties can be produced.

Another class of magnetic oxides, the garnets, are used extensively as magnetic substances at high frequencies. The garnet is a rather complex oxide (compared to ferrites). The garnet crystal can fit several of the rare earths into its lattice. The rare earths have several unpaired inner electrons and therefore have strong magnetic properties. The yttrium-iron garnet is probably the most useful of the garnets at present. Certain devices employing ferrites could formerly be used only at microwave frequencies. The garnet has made it possible to use these devices at frequencies as low as UHF.

NONRECIPROCAL DEVICES

At microwave frequencies, the greatest use of ferrites is in nonreciprocal propagation devices. Nonreciprocal devices can be used to isolate a signal source from its load. A magnetron or other microwave signal source operating into a varying mismatched load (as in the case of a scanning antenna which is fed by a



PROBE COUPLING $TM_{0,1,0,}$ MODE
(A)

LOOP COUPLING $TM_{0,1,0,}$ MODE
(B)

WAVEGUIDE APERTURE
(C)

CYLINDRICAL RING
(D)

AQ. 65

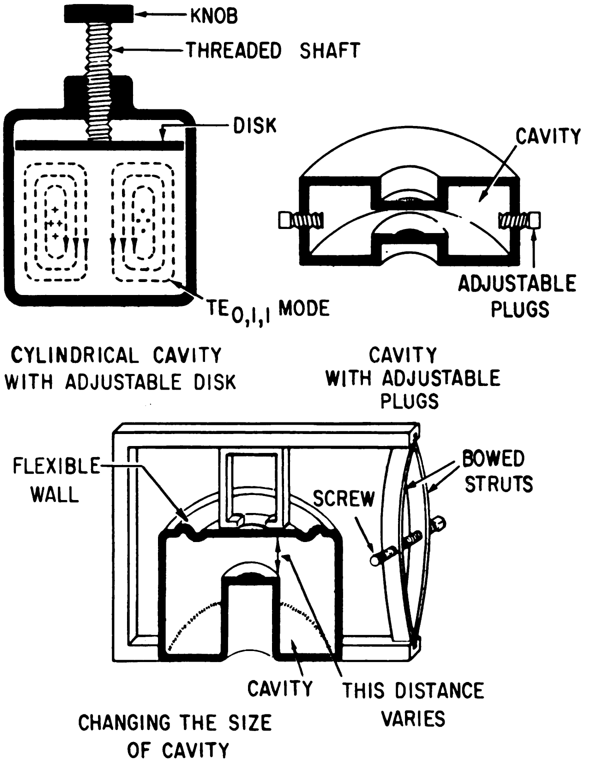
Figure 6-33. –Methods of exciting the cavity.

line with rotating joints) tends toward frequency "pulling." If the reflected energy caused by mismatch is absorbed or diverted before it reaches the source, the source will see a constant load.

Ferromagnetic Resonance

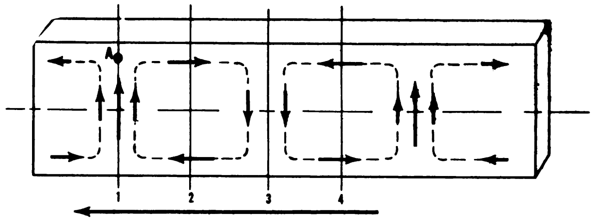
Nonreciprocal ferrite devices make use of the interaction of the electron's spin with an external magnetic field. When a ferrite is placed in an external magnetic field, the atomic "magnets" within the ferrite tend to line up with the external field (i. e., the electrons' spin axes line up with the external field). A spinning electron has gyroscopic properties. When an external force attempts to change the spin axis, the electron precesses. Any gyro has a preferred or natural precession frequency which is proportional to the strength of the external field. By proper choice of ferrite and external field strength, the natural precession frequency can be made to occur at any selected microwave frequency.

An electromagnetic wave traveling down a waveguide will produce, at a point off the centerline of the guide, a rotating magnetic field. This is illustrated in figure 6-35. As the wave advances from right to left, the stationary point A sees a clockwise rotating magnetic field as points 1, 2, 3, and 4 on the moving wave pattern go past. A wave traveling from left to right will produce, at point A, a magnetic field with counterclockwise rotation.



AT 203

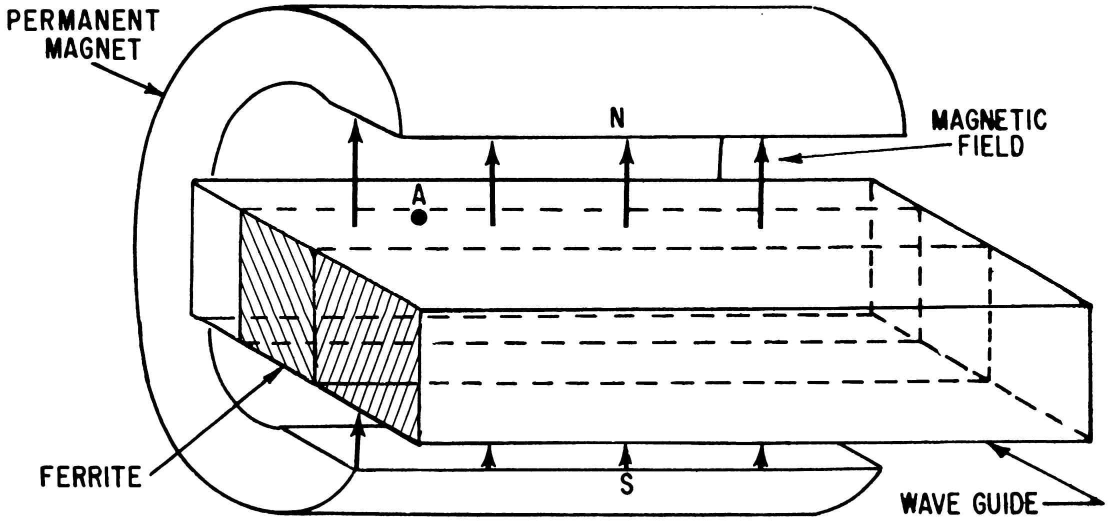
Figure 6-34. –Methods of changing the frequency of a cavity.



AQ. 66

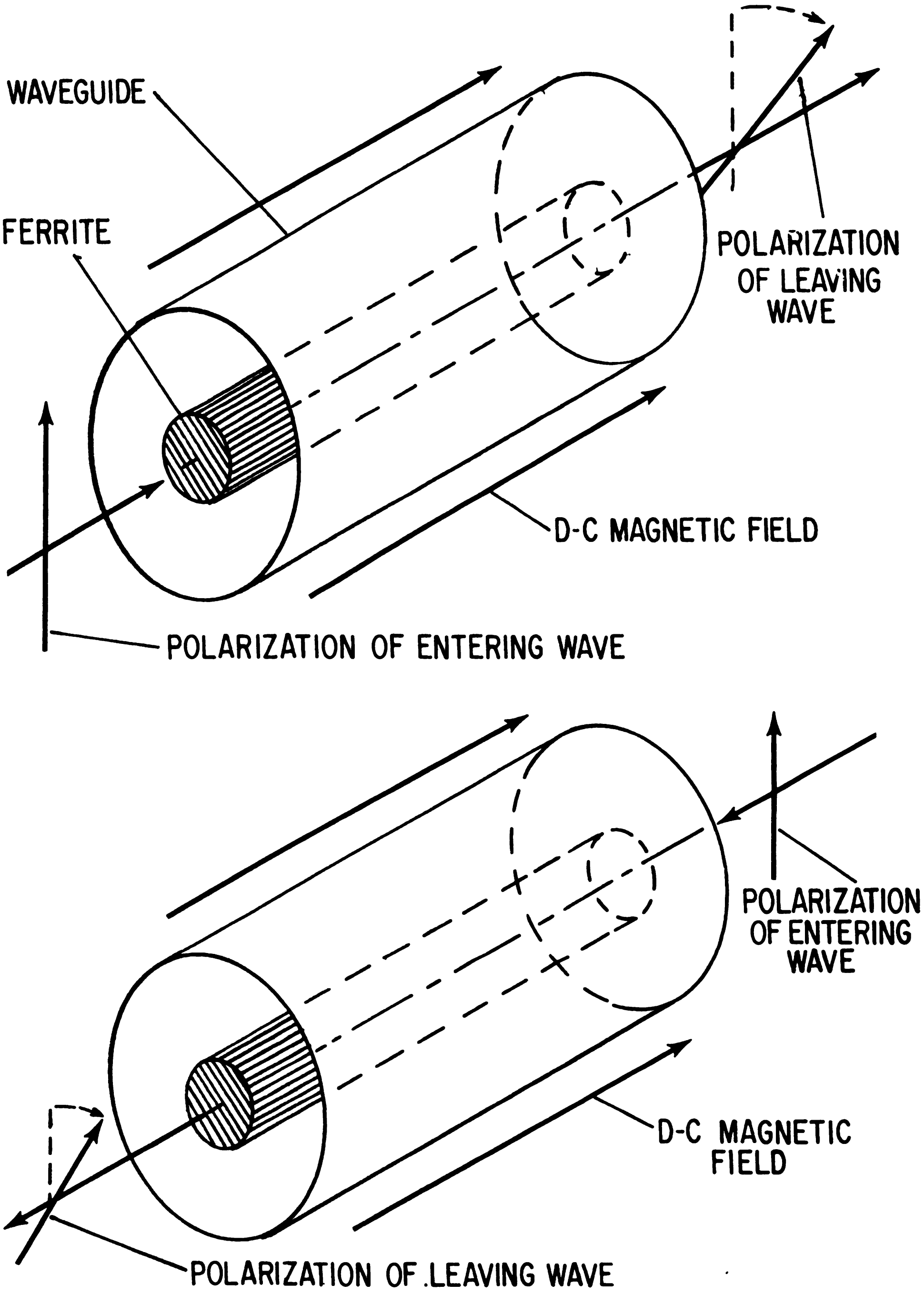
Figure 6-35. –Rotating magnetic fields in a waveguide.

A slab of ferrite placed off center in a waveguide, as shown in figure 6-36, will act as a one-way device at a frequency which depends on the external magnetic field strength. If the ferrite's preferred electron precession frequency matches the frequency of an RF wave traveling from left to right in the guide, the ferrite will absorb most of the energy in the wave; the rotating magnetic field as seen at point A will aid electron precession. The electrons will precess vigorously and convert the RF energy to heat. This phenomenon is known as ferromagnetic resonance. A wave traveling from right to left will be attenuated very little because its rotating magnetic field will oppose electron precession. The one-way device shown in figure 6-36 is a resonance isolator.



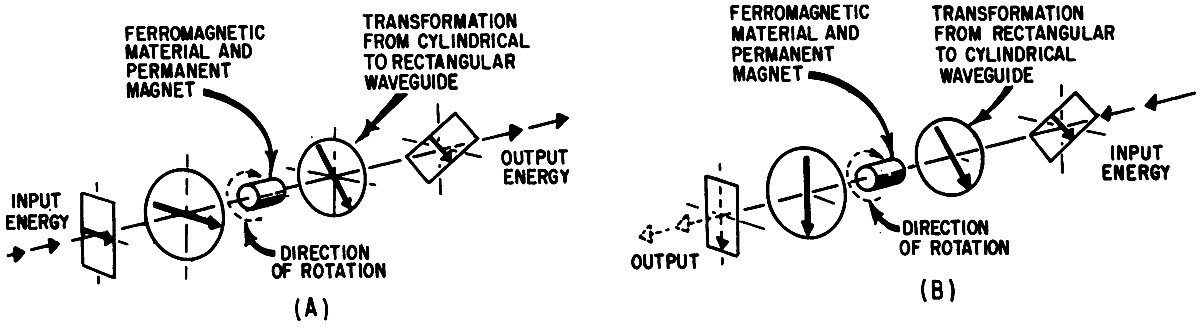
AQ. 67

Figure 6-36. –Resonance isolator.


WAVEGUIDE
FERRITE
POLARIZATION OF LEAVING WAVE
D-C MAGNETIC FIELD
POLARIZATION OF ENTERING WAVE
POLARIZATION OF ENTERING WAVE
D-C MAGNETIC FIELD
POLARIZATION OF LEAVING WAVE

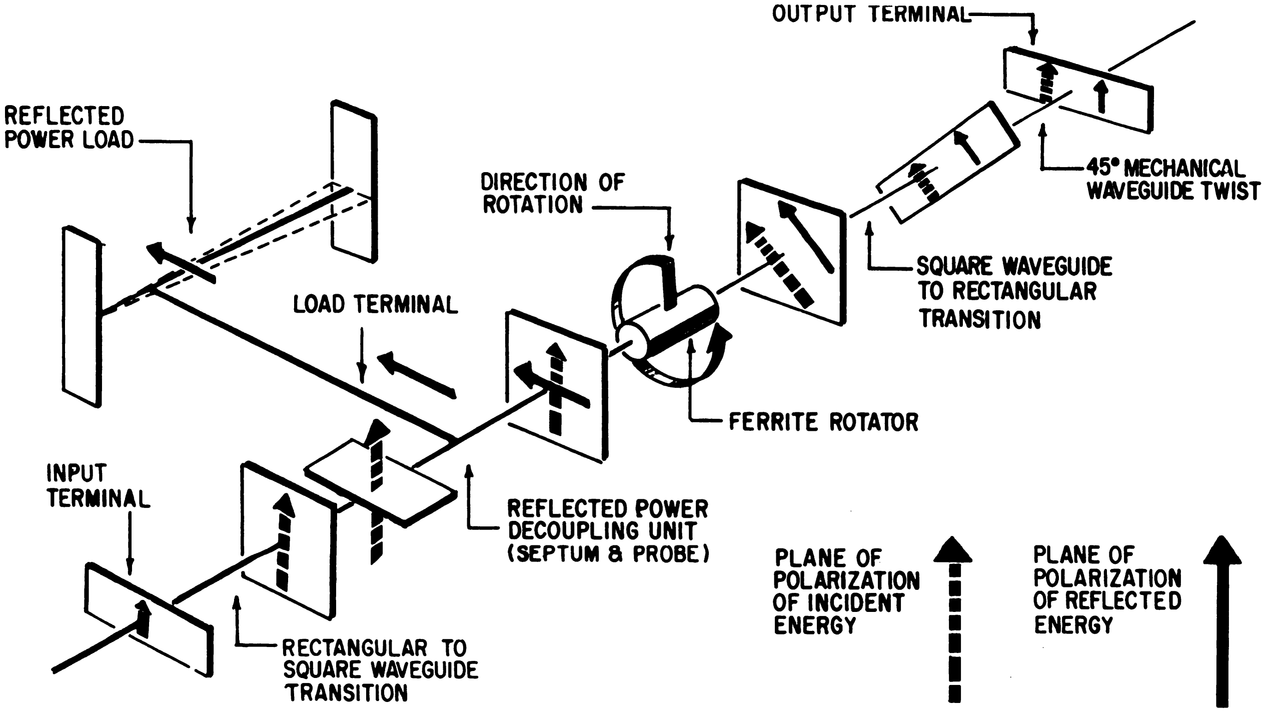
AQ. 68

Figure 6-37. —Faraday rotation.


FERROMAGNETIC MATERIAL AND PERMANENT MAGNET
TRANSFORMATION FROM CYLINDRICAL TO RECTANGULAR WAVEGUIDE
OUTPUT ENERGY
INPUT ENERGY
DIRECTION OF ROTATION
(A)
FERROMAGNETIC MATERIAL AND PERMANENT MAGNET
TRANSFORMATION FROM RECTANGULAR TO CYLINDRICAL WAVEGUIDE
INPUT ENERGY
OUTPUT
DIRECTION OF ROTATION
(B)

AQ. 69

Figure 6-38. –Faraday isolator. (A) Wave traveling in the forward direction; (B) wave traveling in reverse direction.


OUTPUT TERMINAL
REFLECTED POWER LOAD
DIRECTION OF ROTATION
45° MECHANICAL WAVEGUIDE TWIST
SQUARE WAVEGUIDE TO RECTANGULAR TRANSITION
LOAD TERMINAL
FERRITE ROTATOR
INPUT TERMINAL
REFLECTED POWER DECOUPLING UNIT (SEPTUM & PROBE)
PLANE OF POLARIZATION OF INCIDENT ENERGY
PLANE OF POLARIZATION OF REFLECTED ENERGY
RECTANGULAR TO SQUARE WAVEGUIDE TRANSITION

AQ. 70

Figure 6-39. –Faraday isolator with a separate load for absorbing reflected power.

Faraday Rotation

If a plane-polarized wave is propagated through a waveguide containing an axially mounted ferrite rod, the plane of polarization will be rotated when a magnetic field is applied parallel to the direction of propagation. The amount of rotation will depend on the strength of the applied field and the dimensions of the ferrite rod. The sense or direction of rotation will depend only on the polarity of the magnetic field. Figure 6-37 illustrates Faraday rotation.

An isolator which uses the Faraday effect is shown in figure 6-38. A plane-polarized wave comes down the guide and goes through a rectangular-to-round waveguide transition. As the wave passes the ferrite, its plane of polarization is rotated 45° clockwise, and it leaves through the rectangular guide. If a wave comes down the guide in the reverse direction, it will also be rotated 45° clockwise (as viewed from the left) as shown in figure 6-38 (B). The wave will be 90° from the transmission plane of the rectangular guide (the guide will be cut off for this polarization), and the wave will be reflected. Properly oriented vane type absorbers will absorb this energy without affecting waves traveling in the other direction.

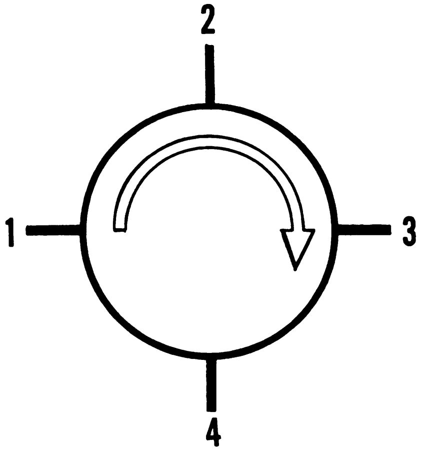
In isolators designed to handle high power, the reflected wave can be coupled out to a separate power absorbing load. An isolator of this type is shown in figure 6-39.

Switches

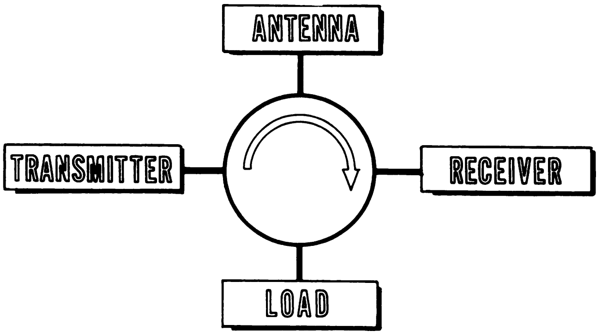
A Faraday isolator can be modified to act as a single pole, double throw, waveguide switch. In the waveguide switch, the output end of the device has two rectangular output guides 90° apart. Each output guide is 45° from the input guide at the other end of the device. An electromagnet supplies the external field. Switching is accomplished by reversing the direction of current flow in the electromagnet. Current in one direction causes the RF wave polarization to be rotated clockwise 45°. Electromagnetic current in the opposite direction causes the wave polarization to rotate 45° counterclockwise. In each case, only one of the output guides will accept the RF wave. Switching times of less than 1 μ sec are possible. Isolation between the output guides (if they are properly terminated) is on the order of 40 db. This type of switch can be used to switch a transmitter between two antennas.

Circulators

A circulator is a device which allows one-way propagation of signals through it. It may have several input-output ports. Figure 6-40 is a schematic of a four-port circulator. The arrow shows direction of power flow within the circulator. Power entering port one leaves by port two only; power entering port two leaves by port three only, and so on. This one-way power flow between ports results from rotation of the signal polarization between ports. Each port is so oriented that it will be cut off for all signals except those which entered the port just before it. Each port, if it is properly terminated, will accept all of the power from the preceding port. Figure 6-41 shows a four-port circulator used as a radar duplexer. The load at port four absorbs any local oscillator signal from the receiver and prevents it from being radiated.



AQ.71
Figure 6-40. –Four-port circulator.



AQ. 72
Figure 6-41. –Four-port circulator used as a radar duplexer.

CHAPTER 7

MICROWAVE TRANSMISSON

The function of the radar transmitter is to develop and deliver the radiofrequency (RF) energy to the antenna for propagation. Most of the aviation fire control radars presently in use are pulse modulated; therefore, the discussion on radar transmitters and associated circuits will be centered around pulse modulated radar systems.

RADAR PERFORMANCE FACTORS

Any radar system has associated with it certain constants. The choice of these constants for a particular system is determined by the tactical use, the accuracy required, the range to be covered, the practical physical size, and the problem of generating and receiving the signal. The effectiveness of a radar set on a particular mission is increased by designing it so that the transmitted pulse has the proper characteristics. The most important characteristics of a radar pulse are its shape, length, and repetition frequency.

PULSE SHAPE

The shape of the pulse determines range accuracy, minimum and maximum range, and resolution or definition of target. The pulse shape is of little importance in the detection of a target as long as it has sufficient power to cause a detectable echo at the receiver. However, the shape of the pulse is very important for range and Doppler velocity measurements. Pulsed Doppler radar depends on the duration of the waveform (pulse width) where it is used in moving target indicators (MTI).

For good range resolution (that is, the ability to separate two targets at nearly the same range), a narrow pulse width is required. If a pulse width of 6 microseconds is used, targets 1/2 mile apart may be resolved. (Remember that 6.18 microseconds equals 1/2 radar mile.) When the two targets are separated by less than 1/2 mile, the leading edge of the pulse will be striking the farthest target while the trailing edge of the pulse is arriving at the closest target. This will cause both targets to appear as one on the scope. Thus the narrower the pulse, the better is the range resolution.

From the foregoing it would seem that an extremely narrow pulse would be desirable. This is not always the case. In order to be detected, a target must return an echo that is strong enough to cause an indication on the scope. The energy in the returned echo may be increased by increasing the peak transmitted power or by illuminating the target for a longer period of time. Longer target illumination may be achieved by increasing the PRF or the pulse width. The peak power that a radar transmitter may produce is limited by the size and quality of its power supply, magnetron, waveguides, and other components. Therefore, it is usually more practical to design a radar with a lower peak power, increasing the pulse width to maintain a sufficient total energy level.

There are also other practical limitations to the minimum pulse width that can be used. Narrow pulses require a receiver with a greater bandwidth. This reduces the gain of the receiver and increases noise.

The ideal pulse with perfectly vertical leading and trailing edges is not attainable. To have perfectly vertical sides (zero rise and fall times) would require an infinite bandwidth. In actual practice, rise and fall times of 10 nanoseconds (0.001 microsecond) are commonplace. The steepness of the leading edge is a predominant factor in the accuracy of range determination. Slope of the trailing edge causes the receiver to remain blanked longer than necessary, reducing minimum range performance.

PULSE REPETITION FREQUENCY

The pulse repetition frequency (PRF) largely determines the maximum range and, to some degree, the accuracy of a radar set. The actual time elapsing between the beginning of one pulse and the beginning of the next, called the pulse repetition period, is the reciprocal of the PRF. Thus, for example, if the PRF is 400 hertz, the pulse repetition period is 1/400 seconds, or 2,500 microseconds. When the frequency is too high—that is, when the period between pulses is too short—the echo from the farthest target may return to the receiver after the transmitter has emitted another pulse, making it impossible to tell whether the observed pulse is the echo of the pulse just transmitted or the echo of the preceding pulse. Such a condition is referred to as range ambiguity.

Although the pulse repetition rate must be kept low enough to attain the required maximum range, it must also be kept high enough to avoid some of the pitfalls a single pulse might encounter. If a single pulse were sent out by a transmitter, atmospheric conditions might attenuate it, the target might not reflect it properly, or moving parts—such as a propeller—might throw it out of phase or change its shape. When it did return, you might blink your eyes just when it would be displayed on the screen and you would not see it at all. Thus, information derived from a single pulse would be highly unreliable; but by sending many pulses, one after another, many good ones will return. The equipment will integrate or sum up the good points of all the pulses and present you with a clear, reliable picture. Equipment is therefore designed in such a way that many pulses (ten or more) are received from a single object. In this way, effects of fading are somewhat reduced. At short ranges, the pulse repetition frequency is increased in order to insure accurate measurements. Many echoes are received from one target, and the integrating effect is increased. This makes possible more accurate range and bearing determination.

Tactical employment of a radar set determines, to a large degree, the PRF to be used. Long range search sets, require a pulse rate slow enough to allow echoes from targets at the maximum range to return to the receiver before the transmitter is again pulsed. Higher pulse rates are used in aircraft interception sets where the maximum range is less.

The following equation will readily determine either the PRF or the range if one of them is known:

$$\text{PRF} = \frac{\text{Speed of Light}}{2 \times \text{Range}}$$

(Multiplying range by 2 converts range to radar range.) Thus a radar with a PRF of 800 hertz could operate to a maximum range of about 100 miles without range ambiguity. Most fire control equipments use 2,000 yards as the standard radar mile; the difference between it and the nautical mile (6,076 feet) is less than 1 percent.

In theory it is desirable to strike a target with as many pulses of energy as possible during a given scan. Thus, the higher the PRF the better. A high PRF combined with a narrow pulse improves angular resolution and range rate accuracy by sampling the position of the target more often. However, we have shown that maximum range limits the PRF.

Power Output

The ability of the transmitter to provide sufficient power is also a limiting factor. Increasing the PRF increases the average power a proportional amount as shown by the equation

$$\text{Average Power} = \text{Peak Power} \times \text{Pulse Width} \times \text{PRF}$$

The useful power of the transmitter is that contained in the pulses and is termed the peak power of the system. Power is normally measured as an average value over a relatively long period of time. Since the radar transmitter is resting for a time which is long with respect to its operating time, the average power delivered during one cycle of operation is extremely low compared to the peak power available during the pulse time. High peak power is desirable to produce a strong echo over the maximum range of the equipment. Low average power enables the transmitter tubes and circuit components to remain cooler while operating and thus can be made smaller and more compact.

Scan Rate and Beam Width

Another factor affecting the PRF is the rate of angular motion of the antenna in searching extensive regions. If the antenna is moved through too large an angle between pulses, not only will the number of pulses per target be too low, but there may even be areas in which targets may exist without their being detected. In this connection, still another factor to consider is the sharpness of the antenna beam. A sharp beam must be pulsed more often than a wide beam to avoid skipping over targets.

The following equation shows the relationship of the antenna beam width, PRF, and antenna scan rate:

$$N_B = \frac{\theta_B f_r}{\dot{\theta}_S} = \frac{\theta_B f_r}{6\omega_m}$$

where θ_B = antenna beamwidth in degrees

f_r = PRF in pps

$\dot{\theta}_S$ = antenna scanning rate in deg/sec

ω_m = antenna scanning rate in rpm

N_B = the number of pulses returned from a point target as the antenna scans through its beam width. (Generally, at least 10 pulses must be returned from a point target for reliable detection probability.)

PRF's of 100 to 2,400 pulses per second are typical of existing aviation fire control radar equipments. RF pulses are usually of short duration, (0.25 to 0.75μsec) giving a long rest period between pulses.

The carrier frequencies, contained within the pulses, are normally from 3,000 to 10,000 MHz (X-band). Sets designed to operate at these frequencies have the advantages of producing narrow beams and using small size RF components.

The block diagram (fig. 7-1) is a simplified drawing and does not refer to any particular type of transmitter; however, it contains the elements found in a majority of aviation fire control radar systems.

The technician should bear in mind that the various components discussed may be physically located in one unit or in several different units, depending on the type of installation.

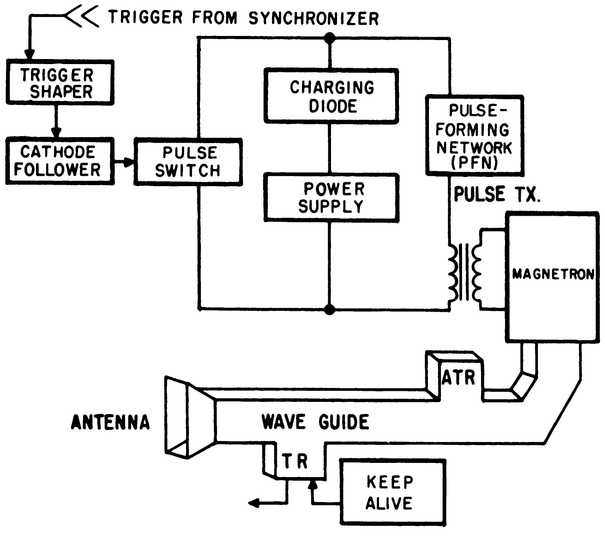


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Figure 7-1.–Radar transmitter (block diagram).

FUNCTIONAL OPERATION

Referring to figure 7-1, the trigger shaper receives an input trigger from the system's synchronizer. As the name implies, the trigger is amplified and shaped into a shape trigger pulse and fed to the next stage, a cathode follower. The cathode follower is used to match the high output impedance of the trigger shaper to the low input impedance of the pulse switch stage. The output from the cathode follower is applied to the control grid of the pulse switch. Before discussing the triggering action, the function of the power supply, charging diode, and pulse forming network are discussed.

The power supply furnishes the high voltage and supplies the energy which the pulse forming network (PFN) stores for release to the transmitter. The PFN, an open end artificial transmission line, stores this energy, and determines the width and shape of the pulse to the transmitter. The charging diode controls the transfer of energy from the power supply to the PFN. The use of an inductive charging impedance causes the PFN to charge to approximately twice the power supply voltage. It also prevents the power supply output from being shorted during the pulse time when the switch tube conducts.

The pulse switch, when triggered, acts like a closed switch which completes the circuit for discharge of the PFN very rapidly through the primary of the pulse transformer. The pulse transformer matches the impedance of the transmitter to the characteristic impedance of the PFN, and thus results in maximum power transfer. Also by using a step-up transformer (from the PFN to the transmitter), a lower voltage may be used on the PFN for a given pulse voltage to the transmitter.

The transmitter is a high powered, high frequency microwave oscillator. It is designed to operate around a predetermined frequency and to be fairly stable at this frequency. It operates during the pulse period and is then shut off for a comparatively long rest period. Its power, in the form of high frequency microwave oscillations, is delivered during the pulse time to the waveguide transmission system for delivery to the antenna, where it is then propagated into space.

The duplexer, which consists of an ATR and a TR, is used to enable the use of one antenna for both the transmit and receive cycle of the system. The TR device effectively blocks the transmitter's energy from entering the receiver during transmit time–the ATR device insures that all reflected energy is directed to the receiver during receive time. The actual construction and operation of the TR and ATR devices were discussed in chapter 6.

This covers the functional operation of a radar transmitter. Prior to the actual circuit analysis of a typical aviation fire control radar transmitter, it is necessary that you first have an understanding of the various transmitter components, their uses, construction, and theory of operation. The following discussion, in conjunction with that found in Basic Electronics, chapters 12, 13, and 15, will prove of great aid in your further understanding of radar transmitters.

PULSE FORMING NETWORK

The type of pulse forming network normally found in aviation fire control radar is the equivalent of an open end artificial transmission line. The network is charged relatively slowly in the time interval between pulses and then discharged suddenly to form the pulse.

A simplified circuit for producing a rectangular pulse by use of an artificial transmission line is shown in figure 7-2. The characteristic impedance of the artificial transmission line is assumed to be 2,500 ohms. (Characteristic impedance of transmission lines is discussed in chapter 12 of Basic Electronics). The resistor R2, across which the output pulse is to be developed, is equal to this characteristic impedance. Resistor R-1, through which the line is charged, is made much larger than the characteristic impedance so that it is an apparent open circuit during the discharge of the line. All the capacitors are charged to 600 volts if switch S is left open for a sufficient time.

If the switch is closed after the line has been charged, a current immediately starts to flow through R2. The line may be considered as a battery with an internal impedance of 2,500 ohms during the discharge time. The equivalent circuit of the artificial transmission line during discharge is shown in figure 7-3. The voltage across R2 is one-half the voltage to which the line was charged or 300 volts, since half the available voltage is lost across the 2,500-ohm internal impedance Z_0. If the network consisted only of capacitors, the discharge would follow an exponential curve, and the voltage across R2 would not be constant. However, the inductance and capacitance of the line are so designated that the discharge rate is practically constant.

The discharge of the artificial line can be explained best as follows: At the instant that the switch (fig. 7-2) is closed, the voltage at point A falls to 300 volts. This can be looked upon as a traveling wave of negative 300 volts applied at point A to reduce the voltage there

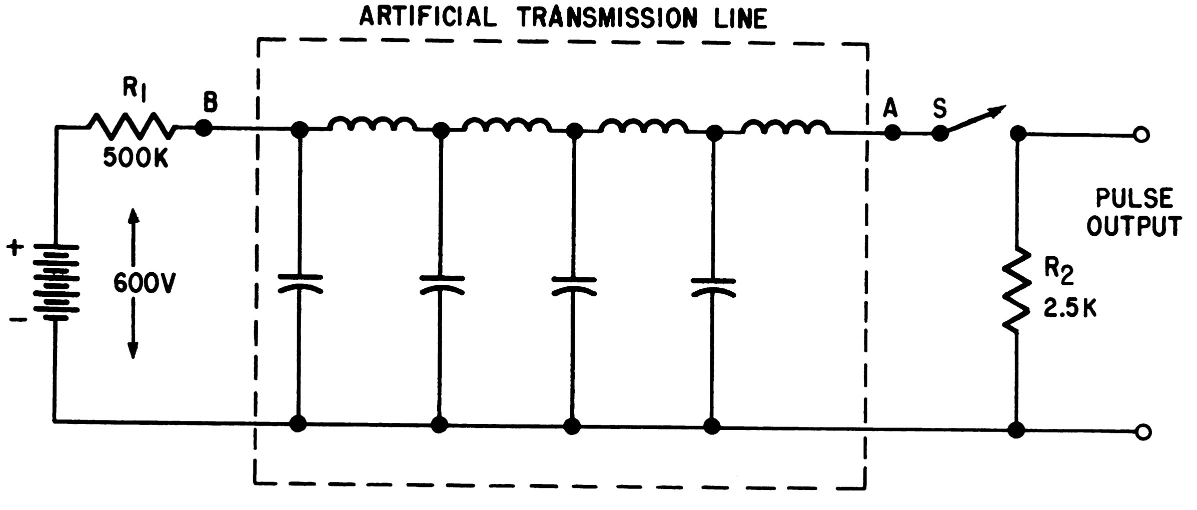

Figure 7-2. –Simple circuit for producing a pulse from an artificial transmission line.

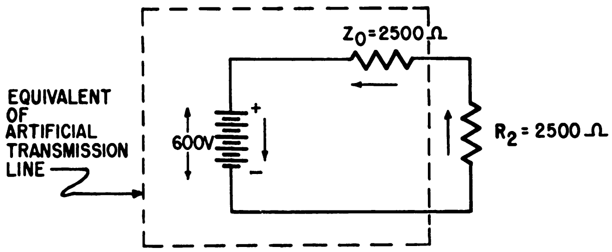

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Figure 7-3.—Equivalent circuit of artificial transmission line during discharge.

immediately from 600 to 300 volts. On reaching point B, the wave sees an open circuit, since resistor R1 is much larger than R2. The wave is reflected without change in polarity, and immediately reduces the voltage at point B from 300 volts to zero as the wave travels back to point A. Thus the remaining 300 volts across the line is canceled out. On reaching point A, the wave has reduced the voltage across sections to zero, the wave itself disappearing because it is absorbed by a load which matches the characteristic impedance of the line. The pulse formed across R2 when the line discharges lasts for the time required for the traveling wave to move from the switch end of the line to the open end and back.

Figure 7-4 illustrates a pulse forming network whose output pulse width may be varied. Switch S1 is provided for adding an additional section to the artificial transmission line, and switch S has been moved to parallel the PFN to facilitate discharge. Usually an artificial line is constructed to produce a variety of pulse widths by the addition of one or more identical sections. When the L and C for each section are known, the time duration of the square pulse t is calculated as follows:

$$t = 2N\sqrt{LC}$$

Where N = number of sections
L = inductance in henries
C = capacitance in farads
t = time in seconds

It should be noted that R2 has been replaced by a transformer (T1) which is used to step up the voltage applied to the magnetron. However, the impedance of the transformer must match the characteristic impedance of the pulse forming network.

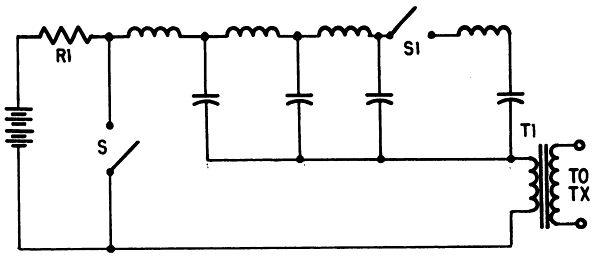

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Figure 7-4.—Variable pulse width PFN.

As an Aviation Fire Control Technician, you will be limited primarily to checking the operation of pulse forming networks and replacing defective ones. The theory of operation just presented may find little application in performing such maintenance, but will be very beneficial in understanding the operation of the remaining transmitter circuits. Application of the pulse forming network is discussed later in this chapter.

MAGNETRON OSCILLATOR AS A TRANSMITTER

A magnetron is used as the transmitting tube in almost all pulsed transmitters that operate at frequencies above 1,000 MHz. The fact that transmit time has little influence on the magnetron, whereas it is a limiting factor in the operation of conventional tubes, makes this type tube desirable for UHF pulses operation. Some triodes may be used in transit-time oscillator circuits at radar frequencies, but their use is limited because of low power output.

Magnetrons are capable of being operated at more than 50 percent efficiency and can produce pulsed power outputs at frequencies as high as 25,000 MHz. The power output of a magnetron may exceed 100 kilowatts at 10,000 MHz and 5 megawatts at 3,000 MHz.

The magnetron, which is a self-excited oscillator, possesses rather poor frequency stability as compared with the more stable lower frequency oscillators (electron coupled or crystal controlled). However, by the use of AFC and proper design, the magnetron provides adequate stability. The magnetron is a type of diode in which a magnetic field is set up perpendicular to the electric field existing between the cathode and the plate. The magnetic field is provided by a permanent magnet. The tube consists of a plate with a cathode placed coaxial with it. The tuned circuits in which oscillations take place are the resonant cavities in the plate. Basic principles of magnetron construction and operation are discussed in Basic Electronics, and in Aviation Fire Control Technician 3 and 2 respectively.

The magnetron tube is a delicate instrument and must be treated as such if satisfactory operation is to be obtained. Handle the tube carefully, for should it be dropped or should the tube elements be moved there is the possibility of a plate to cathode short or at least a change in spacing of these elements. Either of these will cause the tube to operate improperly. The magnets, which are made of a special alloy called Alnico, are unusually strong. The field strength required is dependent upon anode potential and operating frequency. The magnets should not be struck with metallic substances or any hard material for this will cause them to lose magnetism.

Various types of magnetrons have been designed, but at the present time the most used type is the resonant cavity (traveling wave) magnetron. This is the only type that will be discussed in this chapter. The principal component parts of a magnetron are shown in schematic form in Basic Electronics. The plate structure is a solid block of copper in which the resonant cavities are cylindrical holes. A narrow slot opens each cavity into the central portion of the tube and divides the inner plate structure into as many segments as there are cavities. Alternate segments are strapped together so that the cavities are placed in parallel so far as the output is concerned. This makes it possible to take the output from a pickup loop placed inside any one of the cavities. Since the outer conductor of the output coaxial line is at ground potential and connected to the shell of the magnetron, which is a part of the plate structure, there cannot be a high positive d-c voltage applied to the plate. The same result is realized whenever negative voltage is applied to the cathode, since it is equivalent to driving the plate positive.

OPERATION OF THE MAGNETRON OSCILLATOR

The theory of operation of the magnetron is based on the motion of electrons in combined electric and magnetic fields.

Effect of Magnetic Field on Electron Flow

When no magnetic field exists, heating the cathode results in a uniform and direct electron movement from the cathode to the plate surrounding it. (See fig. 7-5 (A).) However, as the magnetic field surrounding the tube is continually increased, a single electron is affected as shown in figure 7-5 (B), (C), and (D). In (B) the magnetic field has increased to a point where the electron proceeds to the plate in a curved rather than direct path. In (C) the magnetic field has reached a value great enough to cause the electron to just miss the plate and return to the cathode in a circular orbit. This value is the critical value of the field strength. In (D) the value of the field strength has been increased to a point beyond the critical value and the electron is made to travel to the cathode in a circular path of smaller diameter. Thus the size of the circle or the path that the electron follows around the cathode for a fixed cathode to anode potential will depend upon the strength of the magnetic field. Since these paths are determined by both magnetic and electric fields, they may be altered by changing the strength of either. The strength of these fields is critical in that they determine the paths the electrons follow. This, in turn, determines the stability of oscillation and tube efficiency. Under ideal conditions the electron paths are such that when curving past the slots of the resonant cavities, energy is released to the RF field.

Principle of Operation

The principle of operation of a magnetron is expressed in the process by which an electron acquires energy from the d-c field (existing between the anode and cathode) and releases it to the RF field to build up and sustain oscillations. (This happens when the d-c field accelerates the electron and causes it to acquire energy proportional to electron velocity.)

The cavity resonators are essentially a number of resonant circuits which are all coupled together. The RF fields of these resonators may or may not be in phase. This phase relationship is determined by the amount of coupling between the cavities. Desired coupling may be acquired by connecting selected segments together. This is known as STRAPPING.

Magnetrons may operate at different modes, which is to say that they may resonate at different frequencies. These frequencies are determined by the velocity at which the electrons whirl about the anode. A mode of operation that produces the greatest power output and effie ciency is the π mode. The resonator is said to operate in the π mode when the phase difference of 180^{0} exists between successive cavities.

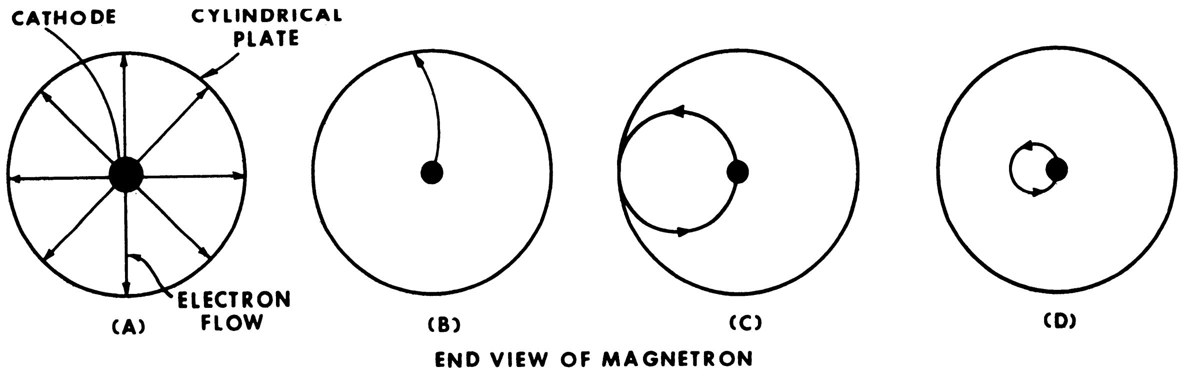

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Fig. 7-5.-Effect of magnetic field on electron.

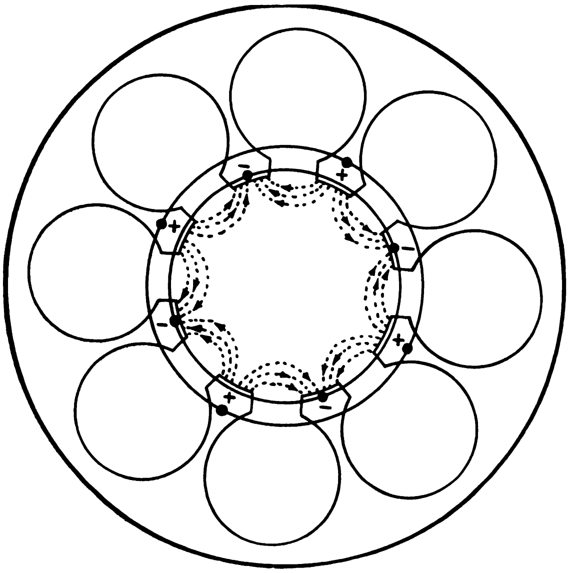

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Figure 7-6.-Electric field distribution in a magnetron.

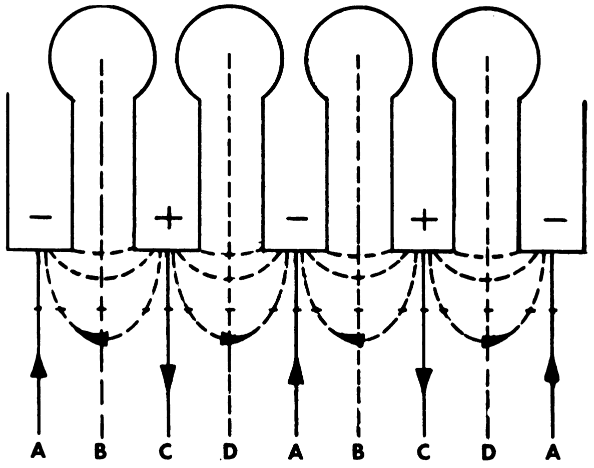

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Figure 7-7.-Force lines in a plane electrode magnetron.

The electric component of the RF field at a given instant may be represented by dotted lines as shown in figure 7-6. In this figure, alternate segments are connected or strapped to maintain a phase difference of 180^0 between segments (π mode). The figure can be redrawn as a plane electrode magnetron with field distribution as shown in figure 7-7. If motion of the electrons in figure 7-7 is considered, an electron at point B is accelerated to the right, one at point C is accelerated vertically, and one at point D is accelerated to the left. This action produces bunching so that bunches of electrons pass the gaps the instant the field causes maximum deceleration. The electrons yield energy to the RF field and induce strong oscillations in the resonant cavity of which the gap is a part.

Since the RF field changes in synchronism with the electron motion, the field lines of figure 7-7 may be considered as a traveling wave moving to the right in synchronism with the electrons. The bunching mechanism produces a spoke shaped cloud of electrons that moves around the cathode in synchronism with the anode wave, as shown in figure 7-8.

As electrons are emitted from the cathode, they combine with the spoke shaped field and

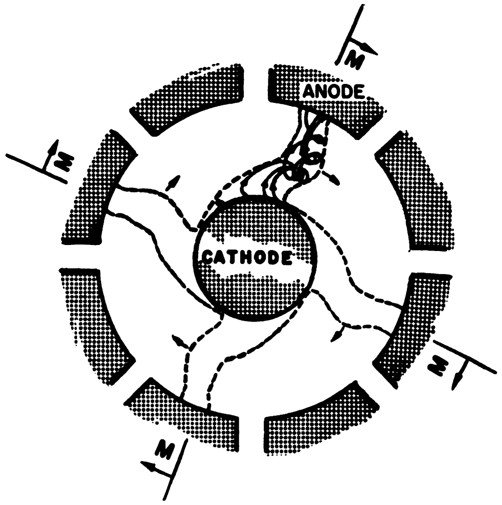

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Figure 7-8.—Orbits of electrons of different phases in a cavity magnetron.

simultaneously spiral towards the anode. Exceptions to this are the electrons that are emitted from the cathode at such time that they absorb energy from the RF fields. These will be quickly returned to the cathode. When electrons approach the opening of the resonant cavity, they will give energy to the cavity provided that the RF voltage across the opening is a decelerating field. (This is illustrated in figure 7-9.) Electrons on the RF negative side of the anode will be repelled by the approaching electrons. This provides the necessary "kick" to the oscillatory action of the cavity and thereby oscillation is sustained. As the electrons pass each cavity, they are slowed down when some of their energy is given up. After a few revolutions their velocity has decreased to the extent that they no longer continue in orbits but are attracted to the anode.

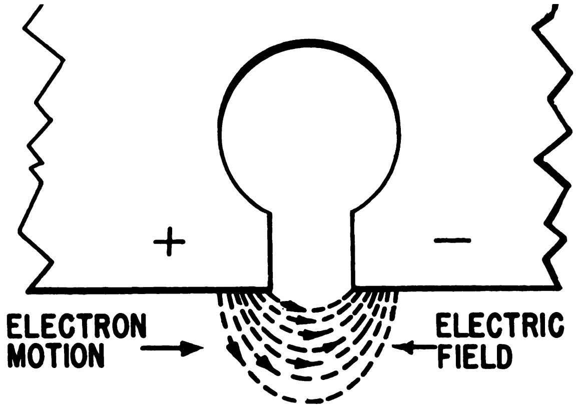

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Figure 7-9.—An electron approaching the slot of a cavity at a time when it will give up energy in the cavity's RF field.

Modes of Oscillation

There are various modes of operation of a magnetron. They are identified by the letter N, which specifies the number of cycles of variation of the field quantities that occur around the circumference of a circle surrounding the cathode. For each mode of oscillation of a magnetron, like those of other cavity resonators, there is a particular pattern of field variations. In the N equals zero mode, since the fields do not enter the anode cavities, the frequency of the mode is not controlled by the cavities; thus, this is an undesirable mode of operation. With the exception of the N equals zero and π modes, all modes are degenerative. The degenerative modes are in reality a combination of two modes that have the same resonant frequency. Due to unavoidable unsymmetrical construction of the anode segments, the degenerative modes separate into two modes of slightly different frequencies.

Since a slight variation may cause a shift from one of these modes of operation to the other with a resultant change in output frequency, these modes are highly undesirable. Since the π mode of operations (previously described) is not degenerative, it is the desired mode of operation.

It is possible in an unstrapped magnetron to have an undesirable mode whose frequency may differ from the π mode frequency by less than 2 percent. The undesired mode will cause interference with the π mode of operation with such a small separation of frequency. With a strapped magnetron it is possible to obtain as much as a 10 percent separation and thus eliminate the interference.

ADDITIONAL FEATURES OF MAGNETRONS

The power output of a magnetron is obtained either by a coupling loop, or by a transformer section of waveguide inserted into a cavity, as shown in figure 7-10.

Cathodes of magnetrons usually are oxide-coated and indirectly heated surfaces. The pulse currents developed in magnetrons are larger than can be produced by thermionic emission alone. The large number of electrons are developed by secondary emission from the cathode as the cathode is back-bombarded by high velocity electrons which are returned by the magnetic field. Metallic cathodes with good secondary emission characteristics have been used satisfactorily. The cathodes are designed with end shields to prevent the escape of electrons from the interaction space between the cathode and anode block. The design of anode blocks depends on the frequency and power output.

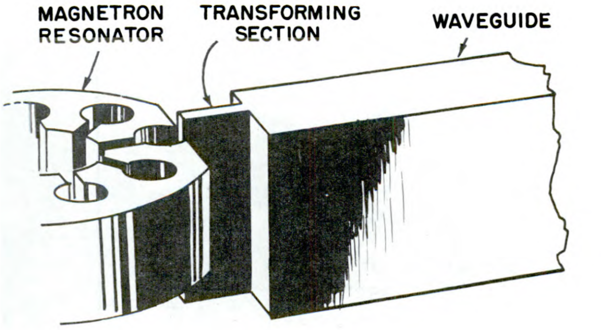

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Figure 7-10.–Waveguide output section.

A type of anode block that can be used unstrapped is called the RISING SUN because of its physical shape. This magnetron, in π mode operation, requires no strapping because its irregular shape contributes to stability.

Magnetrons are difficult to tune. Since the resonant circuits are within the vacuum, they are inaccessible and mechanical tuning is slow. Electronic tuning can be used over a narrow frequency range. Mechanical tuning is done by movement of a mechanical or magnetic device. Ranges of about plus or minus 10 percent of the mean frequency can be obtained by mechanical tuning methods, two of which are shown in figure 7-11. In (A), moving tuning rods are inserted in each of the resonator cavities in order to vary the cavity inductance. These rods are made of a nonmagnetic material. When these tuning rods are inserted into the cavity, they reduce the space available for the magnetic flux and thus the inductance is reduced and the frequency is increased. In (B), tuning is accomplished by varying the capacitance of the resonator. This is accomplished by moving a U-shaped ring in or out of grooves cut into the anode block. When the ring moves into the grooves, capacity increases and the frequency of the magnetron is decreased.

Since much of the heating of the cathode is obtained by the bombardment of the cathode by the electrons returning to it, the filament voltage is usually reduced when the high voltage is applied. This reduction is accomplished by adding a tapped filament transformer or a series limiting resistor in the circuit. In some equipments the filament voltage is removed completely.

Depending upon the type of magnetron and the type of equipment, it is sometimes necessary to season a new magnetron since it may not withstand the immediate application of full power plate voltage. This is accomplished by subjecting the magnetron for a period of a few hours to filament voltage only. After this warm-up period the plate voltage is applied (at low power settings if possible) and a check is made to determine if the magnetron is arcing. Should arcing be detected, it may be necessary to remove the plate voltage and again subject the magnetron to an additional period of seasoning. The Service Instruction Manual will generally contain information in connection with this phase of maintenance.

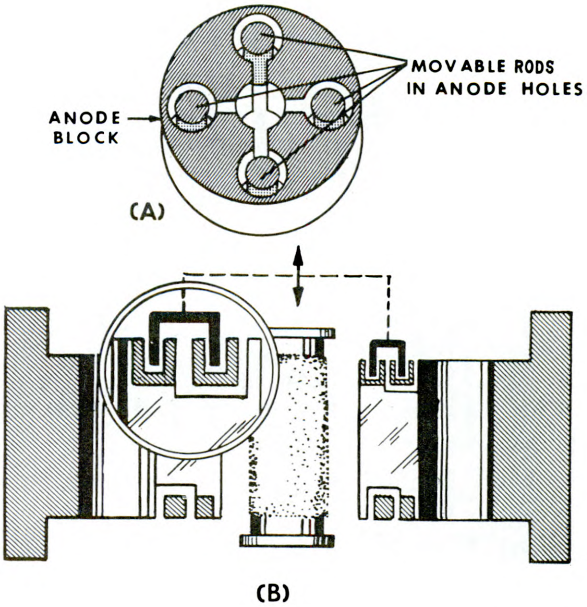

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Figure 7-11.–Two types of tuning methods.

In aviation fire control equipments that use a magnetron, the magnetic field is provided by a permanent magnet. Some magnetrons, called PACKAGED MAGNETRONS, have built-in magnets. The packaged magnetron is finding wide use at the present time.

Theoretically, if the magnetic field of the magnetron is reversed, there should be no change in magnetron operation. This may not always be true since the construction of the magnetron may not be perfectly symmetrical. Thus, after removing a magnet, it is important that it be replaced in its original position. Generally the polarity of a magnet is indicated and this may be used as an aid in maintenance. The magnet should never be removed when the magnetron is operating since this will cause the electrons to strike the anode at high velocity and cause excessive heating. With no magnetic field there is nothing to limit magnetron current.

MULTICAVITY KLYSTRONS

The velocity modulated tube (klystron) theory of operation, as used in radar receivers, is discussed in chapter 12 of Aviation Fire Control Technician 3 and 2 and in chapter 9 of this manual. The following is a discussion of multicavity klystrons used as power amplifiers and as mixers. A brief explanation of the two-cavity klystron and a detailed explanation of the three cavity klystron are given. In addition, this type of power amplifier is compared with the conventional magnetron. It will be seen that the three-cavity klystron, like the two-cavity type, possesses a cathode for emission of electrons, an input cavity, a drift tube, an output cavity, and a collector that is positive with respect to the cathode. The three-cavity klystron differs in the addition of a third cavity in the drift tube, in size, and in gain.

TWO-CAVITY KLYSTRON

Figure 7-12 shows the construction and essential components of a two cavity klystron. In this klystron the indirectly heated cathode emits electrons that are focused into a sharp beam by the control grid, which is at a low positive potential. The beam is then accelerated by a very high, positive d-c potential on grids G2 and G3, which are very close together and connected to a cavity resonator. Superimposed on this d-c potential is an a-c voltage that changes the acceleration of the various electrons differently. Those electrons that reach grids G2 and G3 at a time when the a-c voltage is zero will be accelerated either more or less than normal, depending upon whether the a-c voltage is going positive or going negative at the time they reach the grids.

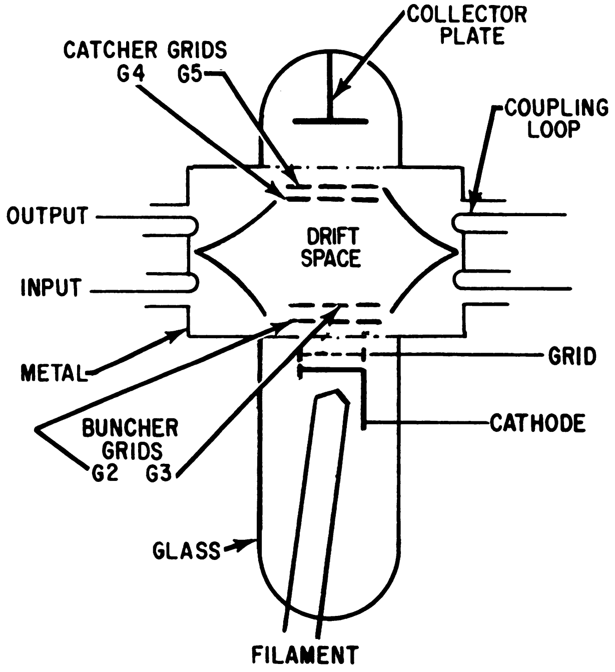

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Figure 7-12. – Two-cavity klystron.

Grids G2 and G3 are called buncher grids because the electrons, which have been accelerated differently, travel at different velocities through the drift space and will bunch at some point. If these bunches of electrons arrive at grid 4 and grid 5 and are there decelerated, they deliver energy to the cavity resonator connected to these grids. Since the function of grids 4 and 5 is to absorb, or catch, the energy contained in these bunches, they are called catcher grids. Electrons that continue through the catcher grid hit the collector plate and are returned to the cathode through an external circuit.

The bunching action that occurs in the klystron is illustrated by the diagram in figure 7-13. In it the lines all start at the top of the diagram at the buncher grids; they represent the paths of the various electrons in their travel through the drift space. The a-c voltage waveshape at the top represents the a-c component of the voltage on the buncher grids; the horizontal axis represents time. The lines are therefore tilted to the right in their passage

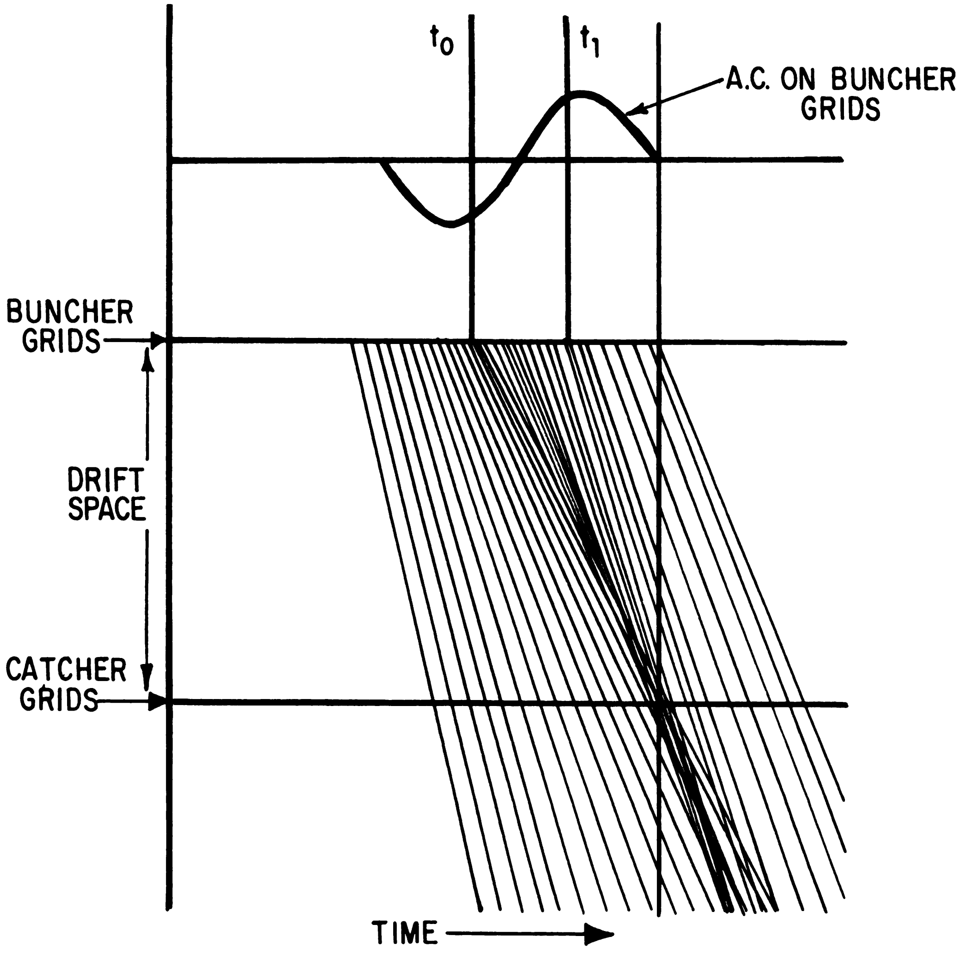

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Figure 7-13.—Two-cavity bunching action.

from buncher to catcher grids. The difference in the slope of the various lines as they leave the buncher grids represents the different velocities of the electrons, which are due to the different accelerations imparted to these electrons by the a-c component of the voltage on the buncher grids. Note that the electrons which arrive at the buncher grids between times t_0 and t_1 form a bunch at the catcher grids. There is only one bunch of electrons in each cycle; hence, the frequency of bunches arriving at the catcher grids is the same as the input frequency.

For the klystron to function most efficiently, the drift space should not be too long. If the distance between catcher and buncher grids is made too great, the bunches disappear or tend to merge, thus making the beam no longer usable. There is a certain spacing that gives best results with given d-c and a-c voltages. Since the spacing (drift space) is fixed in a tube, the voltages must be accurately adjusted for the tube to function properly. Also, the resonant circuit of the catchers must be tuned to the correct frequency. The strength and phase of the oscillation must be such as to absorb maximum energy from the electron bunches.

The a.c., which is superimposed upon the d.c. applied to the buncher grids, may be applied through the input terminal and then by a coupling loop to the buncher cavity. The output may be taken from the catcher with a coupling loop through the output terminal. The klystron power amplifier may be used in pulse operation by applying in pulses the d-c voltage, the RF voltage, or both.

THREE-CAVITY KLYSTRON

In this type, the cathode is heated by an a-c operated heater. The heater and cathode assemblies, with leads brought out at the base of the tube, are insulated from the entrance to the drift tube by a glass insulating sleeve. The input cavity is located close to the drift tube entrance. The middle cavity is located farther along the drift tube, and the output cavity is at the other end of the drift tube. The collector is beyond the output cavity. The entire drift tube assembly, the three cavities, and the collector are at ground potential. This eliminates hazards and complications involved in tuning the cavities, and in liquid cooling of the body and the collector. With the drift tube assembly at ground potential, the cathode is pulsed with a negative voltage to accelerate electrons from the cathode toward the drift tube entrance. The negative pulse is supplied from a pulse forming network and is stepped up to the desired value by a pulse transformer.

In high power klystrons the amplitude of the cathode pulse is measured in hundreds of kilovolts, and the peak current flowing for the duration of the pulse is measured in hundreds of amperes. The high values of accelerating voltages produce dangerous amounts of X-ray radiations, particularly around the collector, where most of the electrons strike. To protect maintenance personnel from harmful radiation effects, the entire klystron is housed in a heavy lead shield. Because of the great current density and the distance of electron travel, electromagnetic focusing is used to control the electron stream.

For a desired RF power output, a certain amount of d-c power must be available. If a peak RF output of 1 megawatt is desired, with an expected efficiency of 33 percent, a peak d-c power input of 3 megawatts is required. The d-c input power is the product of beam voltage and current. The same amount of power can be supplied at high voltage and low current or at low voltage and high current. There is a practical limit to the maximum pulse voltages that can be generated consistently at the PRF's common in modern radar systems. On the other hand, an electron beam of very great density is difficult to control and produces severe focusing problems. The beam voltage and current values used are therefore a compromise between high beam voltage and current density.

The relation between beam voltage and beam current determines the characteristics of the cathode. The cathode characteristic which is of chief importance is PERVEANCE. This is the ratio of cathode current to the beam voltage raised to the three-halves power. It is a measure of the ability of the cathode to emit electrons at various beam voltages, and is determined by the emitting material of the cathode, the cathode area, and the operating temperature.

The impedance presented to the pulse transformer secondary by the klystron during conduction is equal to the ratio of beam voltage to beam current. Since this ratio is determined by the perveance of the cathode, the perveance determines the impedance reflected through the pulse transformer to the pulse forming network supplying the cathode pulses.

Current flows in the pulsed klystron for the duration of the cathode pulse. Between pulses no potential difference exists between the cathode and the drift tube entrance and, therefore, no current flows. The remaining discussion will apply only to the period of conduction, or during the cathode pulse time. When the cathode is pulsed negatively, electrons are accelerated toward the drift tube entrance. The total acceleration given to the electrons by the cathode to drift tube potential resulting from the negative cathode pulse, occurs while the electrons are in transit between the cathode and the drift tube. Figure 7-14 (A) presents an approximate picture of the electric field lines (shown dotted) existing between the cathode and the drift tube entrance.

The electric field lines do not extend into the drift tube for any appreciable distance. With only the electric field present, the electrons would tend to follow the field lines. Under this condition, the electrons would travel from the cathode to the drift tube entrance, and the energy imparted to the electrons by the cathode pulse would be dissipated at the drift tube entrance as heat generated by electron bombardment of the metal surface. To avoid this, a magnetic focusing system is employed to divert the electron stream into the drift tube. Such a field must be symmetrical about the drift tube axis. A few lines of such a field (solid lines) are shown superimposed on the electric field lines of figure 7-14 (A). The focusing action at the drift tube entrance can be seen by referring to figure 7-14 (B). This figure shows a cross section of a magnetic field, which is symmetrical about the drift tube axis. The path of a single electron under the influence of the electric field alone is shown as a heavy solid line.

At point A in figure 7-14 (B), where the

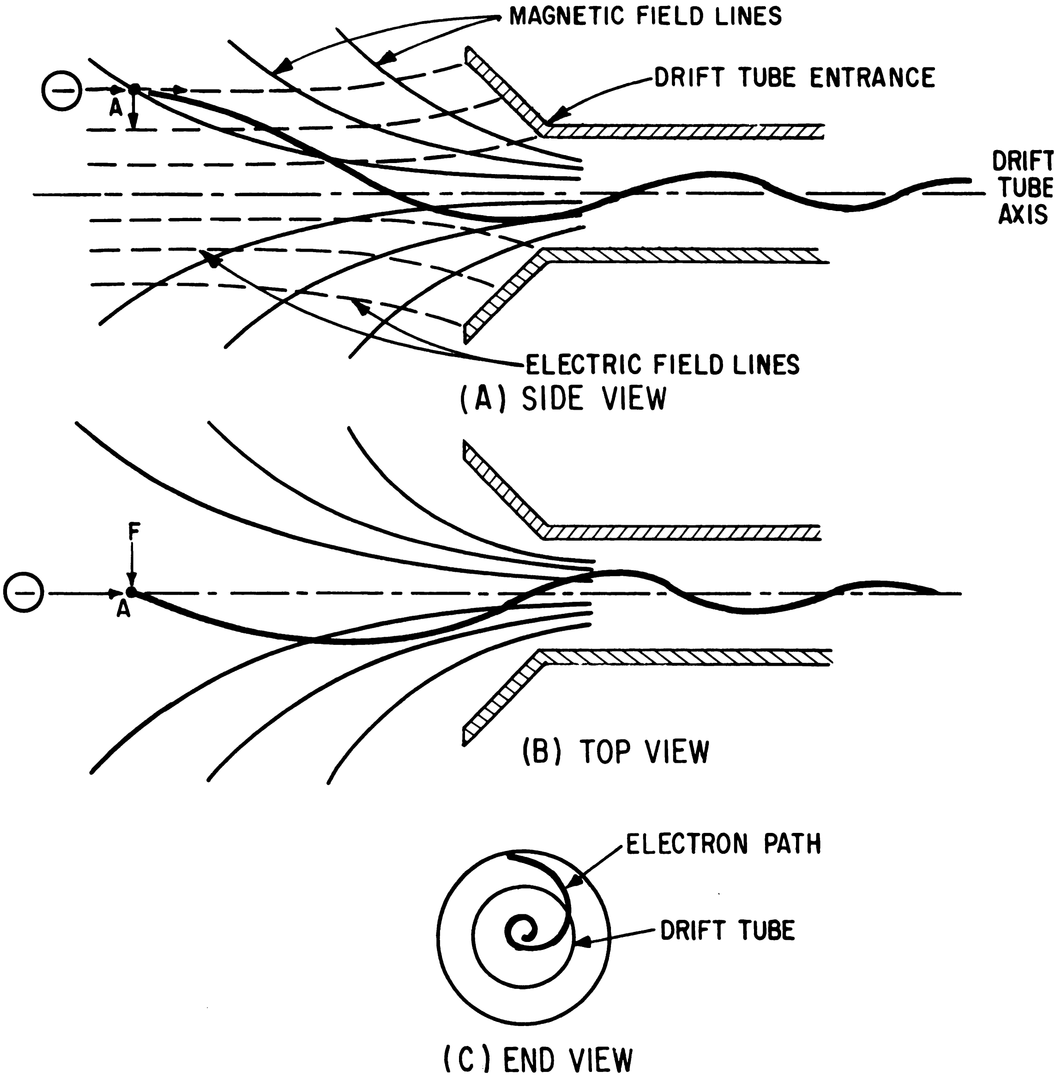

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Figure 7-14.-Convergence of electron stream of entrance of drift tube in klystron.

electron path intersects a magnetic field line, the line is resolved into its components. One component (axial component) is seen to be parallel to the direction of the electron path and another (radial component) is at right angles to the electron path. The radial component force causes the electron to rotate out of the plane of the figure, around the axis of the drift tube. This tangential force causes the electron path to become helical as it approaches the drift tube entrance. At the drift tube entrance the magnetic field intensity is much greater than that at the cathode, causing the spiral of the electron path to become tighter about the drift tube axis. Also, at the drift tube entrance, the magnetic field lines are almost entirely axial.

The tangential component of the electron velocity in the presence of the axial field causes the electron to be accelerated radially inward. The electron path as viewed from the cathode end of the drift tube is shown in figure 7-14(C). The greater the initial distance (perpendicular) of the individual electrons from the drift tube axis, the greater the forces tending to direct the electrons toward the drift tube axis. Electrons released from the cathode at or near the drift tube axis experience relatively slight effects of the magnetic focusing field and travel an almost straight line path from the cathode to the drift tube entrance. The overall effect of the magnetic field is to force electrons emitted from the cathode into the drift tube, thus keeping to a minimum the number striking the metal surrounding the drift tube entrance.

Once the electrons enter the drift tube, they are no longer under the accelerating effects of the cathode to drift tube potential, and they coast, or drift, at constant speed until they encounter the fields across the gaps of the three resonant cavities arranged along the length of the drift tube. The axial field produced by the entire focus coil assembly extends the length of the drift tube. The electrons within the drift tube travel parallel to the axial magnetic field. Whenever, for any reason, an electron is deflected from the axial path, a radial component of velocity is introduced that causes the electron to spiral about the axial magnetic lines. It is impossible to provide the degree of focusing required to prevent all electrons from striking the walls of the drift tube. By proper adjustment of the magnetic field, however, it is possible to hold the number to a practical minimum.

Current produced by electrons striking the drift tube walls is referred to as body current. A high body current is undesirable since it indicates that a large number of electrons are giving up energy as heat in collisions along the drift tube walls rather than contributing energy to the RF output cavity. Several factors influence the amount of body current produced. The most important is the focusing adjustments. Another is the interaction of electrons in a dense electron stream. Since all electrons are negatively charged, they tend to repel each other; this produces beam spreading and subsequent collisions along the drift tube walls. Another effect is also produced by the concentration of negative charge within an electron stream.

Electrons along the outer edges of the stream see a concentration of negative charge at the center of the stream (corresponding to the drift tube axis). The drift tube walls, being at ground potential, appear positive with respect to the concentrated charge along the axis of the tube. The fringe electrons are, therefore, accelerated toward the drift tube walls because of this apparent potential difference between the center of the drift tube and the walls.

As previously stated, electron behavior is influenced by the cavity gap voltages once the electrons have entered the drift tube. Cavities of the gridless type are used because of the unusually great electron velocities produced by the high beam voltage. The edges of the cavity gaps are flush with the drift tube wall to avoid intercepting electrons in the beam.

Cavity resonator construction for klystron tubes is of two primary types. One type is built into the tube and is evacuated as part of the tube structure. Tuning of this type of cavity is performed by some type of bellows driving mechanism that alters the physical size of the cavity. Another type of cavity is mounted externally to the evacuated tube section. The portion of the drift tube comprising the resonant cavity gap is a cylinder of ceramic or other low loss insulating material. The tuned cavity can be removed from the drift tube in such an assembly.

The chief factor in cavity gap spacing is electron transit time. The ideal condition is zero transit time but, of course, this is not possible at the desired operating frequencies. There is a finite time interval involved in the passage of electrons across the gap of the resonator. The time required for passage is determined by the initial electron velocity upon entering the gap and upon the width of the gap. The operating frequency determines the passage time required in terms of a complete RF cycle. If the width of the gap is made very small to reduce transit time, the cavity impedance is lowered, since this is equivalent to increasing the capacitance of a tuned parallel resonant circuit. Also, if the gap is made very small, possibility of a breakdown across the gap exists, because of the large RF voltages developed.

In addition, with a small gap there is heavy loading of the cavity. This is a result of secondary electrons, emitted around the cavity gap, being driven across the gap by the RF potentials across the gap. Movement of these electrons under the influence of the RF field across the gap is an energy drain on the cavity and performs no useful function. This waste of energy is reflected as a reduced Q of the cavity with associated losses in power. A cavity gap that produces a transit time of a quarter cycle or slightly more at the operating frequency provides satisfactory beam coupling, and at the same time, avoids the undesirable effects of too small a gap spacing.

The drift tube diameter is also a compromise. While a small diameter gives a high degree of coupling between the cavities and the electron beam, it complicates the focusing problem. A large tube diameter simplifies the focusing problem but reduces beam coupling.

However, the diameter of the drift tube must be less than the cutoff dimension at the operating frequency. This is necessary to avoid standing waves along the drift tube. The drift tube diameter is, therefore, a compromise value that gives satisfactory beam coupling to the cavity gaps and at the same time permits practical focusing of the beam.

The output of any klystron (regardless of the number of cavities employed) is developed by velocity modulation of an electron beam. Velocity modulation, in turn, produces electron bunching. The bunching process is a result of the velocity modulation, and is a function of the time required for electrons to travel the distance from the input cavity to the output cavity. The electrons that are initially accelerated by the beam voltage (considered to be d. c. for the duration of the cathode pulse) are acted upon by RF fields developed across the input and middle klystron cavities.

Some electrons are accelerated, some are decelerated, while others are unaffected, depending on the amplitude and polarity of the cavity RF voltages when the electrons cross the cavity gaps. For the interval during which the electrons travel from one cavity to the next, the accelerated electrons tend to overtake the decelerated ones, thus causing the formation of groups, or bunches, of electrons. As a result, bunches of electrons arrive at the output cavity at the proper instant of each RF cycle to deliver energy to the output cavity. Transit time is thus seen to be a necessity rather than a hindrance to the klystron operation.

Bunching

The bunching process is best explained by reference to figure 7-15, a diagram of the bunching process in a three-cavity klystron. The vertical axis represents the distance measured along the drift tube. The horizontal axis represents time measured either in millimicroseconds or in degrees of an RF cycle. The diagonal lines are electron paths plotted as a function of time and of distance along the tube.

The slope of a line is proportional to the velocity of the electron whose path is described by that particular line. The steeper the slope, the greater the electron velocity. Between the cathode and the first cavity the electrons emitted from the cathode receive equal accelerations and therefore travel at equal velocities. All electrons entering the input cavity gap thus have equal slopes.

A sinusoidally varying RF field exists across the first (input cavity) gap as a result of the signal input supplied from an external RF source. The input cavity is resonated at the input frequency. The effects of the RF voltage across the input cavity gap on individual electrons depend upon the instantaneous magnitude and polarity of the RF gap voltage. The word "instantaneous" implies that the transit time is zero. As previously explained, this is not true, since an appreciable portion of an RF cycle (over one quarter) elapses during the electron transit across the gap. More correctly, the average magnitude and polarity of the RF cycle during the electron transit must be considered.

An electron, designated as electron 1 in figure 7-15, crosses the input cavity gap when the potential is zero. The velocity of electron 1 is unaffected by the input gap voltage and there is no change in its velocity. This is shown by no change in the slope of the line describing the path of electron 1. Electron 3 crosses the input cavity gap when the RF voltage is maximum in a negative direction. This electron is decelerated during its passage through the gap and emerges from the gap traveling at a reduced velocity. This is indicated by a decrease in the slope of line 3 beyond the input cavity.

Electron 5, like electron 1, passes through the gap when the RF signal is zero and therefore emerges with no change in velocity. Electron 7 crosses the input gap when the RF voltage is maximum in a positive direction. This electron is accelerated during its transit through the input gap and emerges from the gap at increased velocity. This is indicated by an increase in the slope of line 7 beyond the input cavity gap. Electrons 2 and 4 cross the input gap when the RF voltage is negative and are decelerated by an amount proportional to the amplitude of the RF voltage. Electrons 6 and 8 cross the input gap when the voltage is positive and are accelerated by an amount proportional to the amplitude of the RF voltage.

When the electrons pass the input cavity gap, they enter the drift tube section between the first and second cavities. In this region there are no d-c or RF fields and the electrons travel at whatever velocities they acquired as a result of the combined effects of the beam voltage (cathode pulse) and the RF voltage across the input cavity gap. In passing through the first gap, electrons emitted from the cathode at successive intervals are accelerated or decelerated as explained above. This process is called velocity modulation. In the drift tube

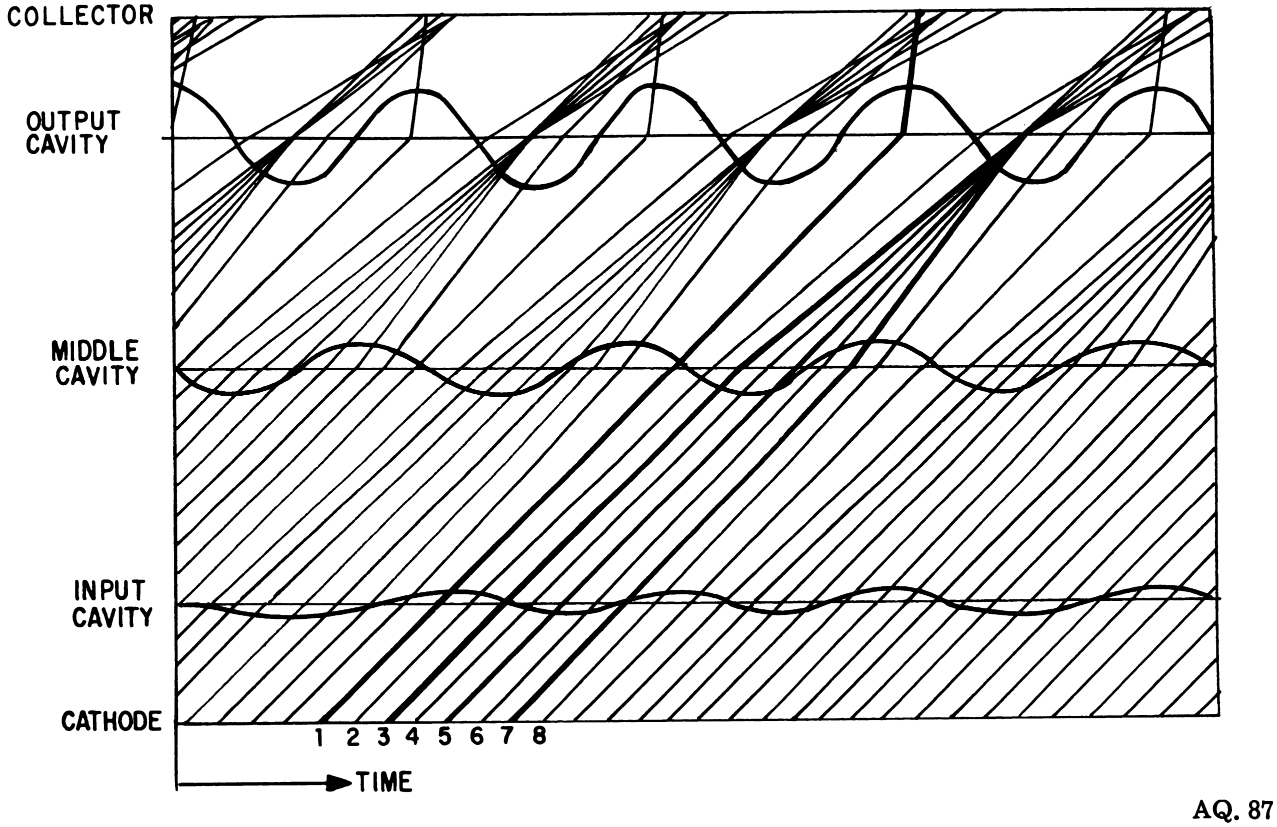

Figure 7-15. —Graph of klystron bunching.

section, between cavities one and two, the velocity modulation produces density modulation of the beam.

Electron 3 leaves the cathode earlier than electron 5. Initially, both have the same velocity. Since electron 3 is decelerated in passing through the input cavity gap and electron 5 is unaffected, electron 5 will overtake electron 3 if the two drift for a time in a space where no fields are present. Electron 7 is emitted from the cathode at a later time interval than electron 5, but both have the same initial velocity. Electron 5 is unaffected by the RF voltage across the input cavity gap, but electron 7 is accelerated. Therefore, electron 7 will eventually overtake electron 5 if they travel undisturbed for a sufficient time. The overall effect is that electrons crossing the input cavity gap before and after electron 5 tend to converge on, or group around, electron 5. This is slightly evident at the middle cavity.

Velocity modulation of the d-c beam by the input cavity does not produce serious loading of the input cavity. The fact that a d-c beam is being velocity modulated means that the number of electrons crossing the input cavity gap when the RF voltage across the gap is negative is equal to the number crossing the gap when the RF voltage across the gap is positive. If electrons cross the cavity gap when the RF voltage across it is negative, energy is supplied to the cavity by the electrons, because in slowing down, the electrons give up kinetic energy to the gap. If the electrons cross the cavity gap when the RF voltage across it is positive, energy is supplied to the electrons from the cavity, since the electrons are accelerated. The RF input to the first cavity, therefore, is of sufficient magnitude to overcome the inherent losses in the cavity in maintaining the desired RF voltage across the cavity gap.

Only a small degree of density modulation (bunching) occurs within the electron beam in the interval of travel from the input cavity to the middle cavity. The amount is very small compared to the degree of bunching required at the output cavity. The amount of density modulation is sufficient, however, to excite the middle cavity and, because of the high Q of this cavity, to maintain a large oscillatory voltage across it. The voltage thus produced across the middle cavity gap is much larger than that across the input gap. This voltage is responsible for most of the velocity modulation, and subsequent density modulation, produced within the klystron.

There is a negligible net transfer of energy from the beam to the middle cavity, or from the cavity to the beam. The amount of energy coupled to the cavity from the beam is the small amount necessary to overcome the cavity losses in maintaining the oscillatory RF voltage across the gap. The degree of density modulation present in the electron stream at the middle cavity, as a result of the velocity modulation at the input cavity, is so slight compared to that required at the output cavity that it can be considered as d. c. for practical purposes. Therefore, the net energy delivered to, or taken from, the electron beam is quite small, as explained for the input cavity.

The large voltage across the middle cavity gap produces a much larger degree of velocity modulation than that of the input cavity. This is evident in the diagram of figure 7-15 by sharper changes in the slopes of the electron paths crossing the middle cavity. Electrons 1 and 5 again cross the gap when the RF voltage is zero, and continue with no change in velocity. Electrons 2, 3, and 4 cross the gap when the RF voltage is negative and are slowed down, as shown in a decrease in slope of lines 2, 3, and 4. Electrons 6, 7, and 8 cross the gap when the RF voltage is positive and are accelerated, as shown by increases in the slopes.

After the electrons cross the middle cavity gap, they once more drift in the field region between the middle cavity and the output cavity. The bunching process continues in this region, but at a more rapid rate than that between the input cavity and the middle cavity because of the greater degree of velocity modulation imparted to the beam by the middle cavity. The effect of velocity modulation is shown at the output cavity. Electrons 3, 4, 5, 6, and 7 are bunched and cross the output cavity gap when the gap voltage is maximum negative. Under this condition, maximum energy transfer from the electrons to the output cavity occurs.

The energy given up by the electrons is the kinetic energy of high velocity, imparted to the electrons by the beam voltage (cathode pulse). Giving up this energy produces a decrease in velocity as shown by the sharp changes in slopes at the output cavity. Electrons 2 and 8 do not receive sufficient velocity modulation to cause them to bunch with the others. Electron 1, having traveled unaffected through the input and middle cavities, reaches the output cavity when the RF voltage across it is maximum positive. The voltage imparts to the electron a sharp acceleration. This is shown by the sharp increase in slope. This acceleration of electron 1 represents a load on the cavity, since energy from the cavity is required to accelerate the electron.

Optimum bunching reduces the number of such electrons to a minimum. The bunching process pictured in figure 7-15 is ideal, particularly at the output cavity, as the bunched electrons are shown arriving at the output cavity, at the same instant. This is not true in practice. The passage of an electron bunch at the output cavity occurs over a period covering a considerable portion of a half cycle. Also, the history of only eight electrons is discussed. Actually, billions of electrons are emitted from the cathode during the time interval between the emission of electrons 1 and 8. The effects of mutual repulsion produced by such a dense electron stream make it impossible to approach, in practice, the degree of bunching shown in figure 7-15.

Since it has been stated that the bunching process is a function of time, it would appear that if an electron beam is velocity modulated by a small RF voltage and the electrons are permitted to drift for a sufficiently long time, the desired degree of bunching could be obtained with a minimum of input power. The defocusing effects previously discussed prevent this, however. The debunching effects of a dense electron stream would spread the beam in the drift space after a short time interval. The drift time is therefore limited to a time interval corresponding to only a few RF cycles, and input power is adjusted to produce the desired bunching in this time interval.

The three-cavity klystron is the equivalent of a pair of two-cavity klystrons in cascade, and is referred to as a cascaded amplifier klystron. The three-cavity klystron is more efficient than a pair of two-cavity klystrons in cascade, since the middle cavity replaces the output cavity of one pair and the input cavity of the other. In this way cavity losses are cut in half and the further division of power produced is avoided. (A maximum of 50 percent efficiency is realized when a matched source and load are coupled.) Another advantage is the simplified circuitry involved. There are only three tuned circuits instead of four; one electron beam is used, and power supply provisions are also simplified.

To summarize, the mechanics of bunching with a klystron cause the output power to be critically dependent on input power. For a given frequency, drift tube length, and beam voltage, there is only one value of input power that gives maximum output if all three cavities are tuned for maximum gain. The degree of bunching achieved in a given drift tube space depends on the amount of velocity modulation imparted to the beam electrons while crossing the gaps of the input and middle cavities. The velocity modulation depends on the amount of RF voltage appearing across the input and middle cavity gaps.

The greater the voltage developed across the input cavity gap, the greater the velocity modulation produced at this gap and the greater the degree of density modulation produced at the interval of electron travel from the input cavity to the middle cavity. The excitation of the middle cavity depends on the amount of density modulation in the beam arriving from the first cavity. The greater the density modulation seen at the middle cavity gap, therefore, the greater the RF voltage developed across the middle cavity gap, and the greater the velocity modulation imparted to the beam. If the input power is at the optimum value, the maximum bunching point will occur at the output cavity gap.

If the input power is too low, there is insufficient velocity modulation of the beam, and maximum bunching will occur slightly later, or at a point beyond the output cavity gap. If there is too much input power, too large a degree of velocity modulation is produced, and maximum bunching occurs before the velocity modulated electrons reach the output cavity. The amount of bunching at the output cavity determines the power delivered to the cavity from the electron beam. Either of these conditions, overdriving or underdriving the input cavity, produces maximum bunching in the klystron at some point along the drift tube other than the output cavity gap with a resulting decrease in output power. A curve of klystron power output versus power input is shown in figure 7-16.

PERFORMANCE

Another consideration is expressed in the curves of figure 7-16. The power output of a three-cavity klystron can be increased beyond that corresponding to maximum gain (all three cavities tuned to the same frequency). The bunches of electrons arriving at the output cavity contain components contributed by velocity modulation produced both at the input cavity and at the middle cavity. With all three cavities tuned to the same frequency, the bunched current contributed by velocity modulation at the input gap is not ideally phased with respect to the velocity modulation contributed by the middle cavity f_2; therefore, the bunching components of the input cavity do not add with those of the middle cavity to produce optimum bunching at the output cavity. This is shown by the curve labeled $\Delta f_2 = 0$ MHz.

By detuning the middle cavity ($\Delta f_2 = 1$ MHz), the components contributed by the input cavity are phased more advantageously with respect to those contributed by the middle cavity, and the bunching at the output cavity is increased. When the second cavity is detuned ($\Delta f_2 = 2$ MHz) to further change the phase of the RF voltage across it with respect to that across the input cavity, the amount of density modulation required to maintain a given RF voltage across the middle cavity gap is increased. Since the density modulation appearing at the middle cavity is a result of the velocity modulation contributed by the input gap, the power supplied to the input gap must be increased to supply the required increase in velocity modulation. Further detuning of the second cavity ($\Delta f_2 = 3$ MHz) results in a further increase in output power, provided that the input power is increased to the new required value.

The curves of figure 7-16 show the results obtained with various amounts of detuning of the middle cavity. Notice that the increase in output power is not proportional to the increase in input power required to maximize the output for a particular degree of middle cavity detuning. Increases in output power obtained by detuning the middle cavity and increasing the input power are obtained at a sacrifice of gain. At the higher power outputs obtained by detuning the middle cavity, the output curve is much broader, and the klystron output is less critically dependent on variations of input power.

The final major consideration in power klystron performance is the shape of the cathode voltage pulse. The amplitude of the pulse determines the transit time of the electrons from

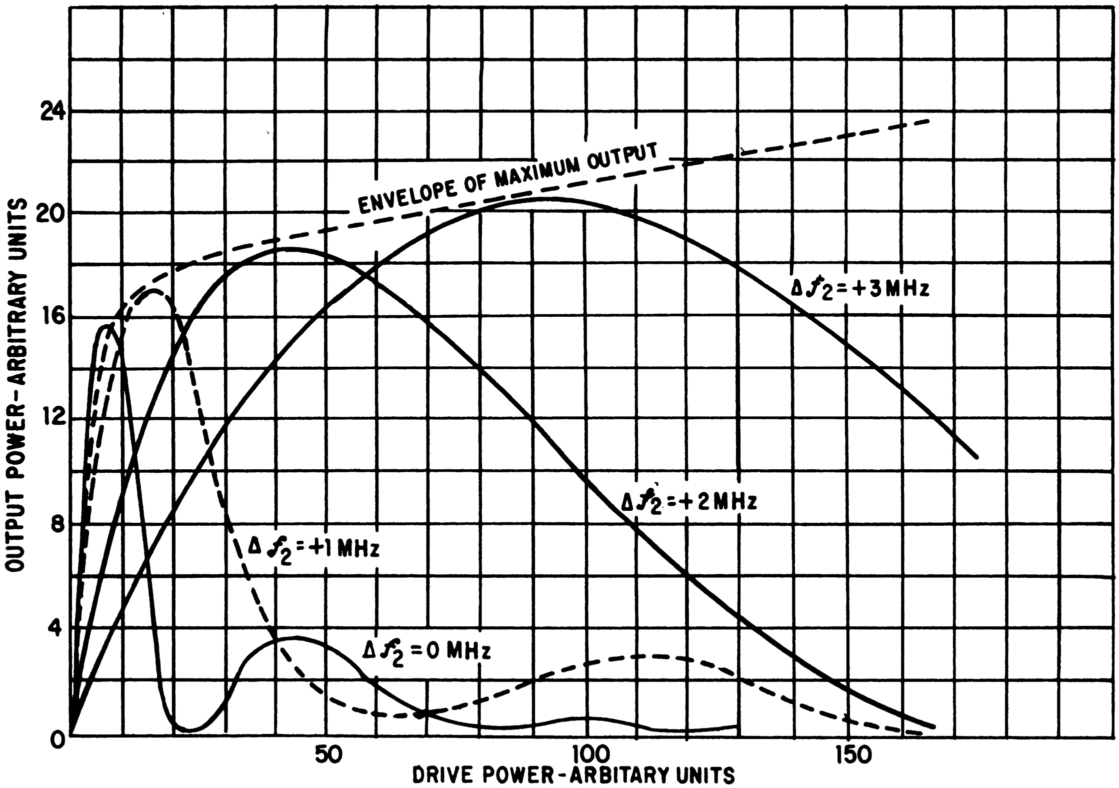

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Figure 7-16.–Graph of klystron input versus output power.

the cathode to the collector. Any change in pulse amplitude affects the electron transit time. This, in turn, affects the points of occurrence of maximum electron bunching in the region of the output cavity. If the RF input to the klystron is constant and the cathode pulse amplitude varies over the duration of the pulse, the points of occurrence of maximum bunching will vary with pulse amplitude. This results in phase shift of the RF signal output with respect to the input during the cathode pulse.

Since the transit time from the input cavity to the output cavity is usually equal to the time of several RF cycles, a small percentage phase shift may still be undesirably large. Any phase shift is undesirable in a moving target indicator system, which yields information based on pulse to pulse phase comparisons. Phase shift of the RF output must therefore be held to a value that will not limit the moving target resolution possible in the cancellation system employed in the equipment. Thus the cathode voltage pulse must be flat topped.

KLYSTRON VERSUS MAGNETRON

The advantages of the klystron as compared to the magnetron are many. First of all, physical considerations are simplified. In the magnetron, the cathode and the anodes are included in the frequency determining system and are a compromise between desired power output and required size. In the klystron, the cathode and collector are external to the frequency determining fields and can be designed independently of the RF section to handle the desired power. Cooling methods are simplified, since most of the heat generation occurs in the collector and can be dissipated by a cooling system without consideration of the RF portion of the tube. Figure 7-17 illustrates a three-cavity klystron.

From the standpoint of electrical performance, the klystron again excels. The magnetron is a power oscillator and is the frequency determining element of the radar system. Its frequency stability is dependent on the combination of a magnetic and an electric field, either of which is subject to variations over short

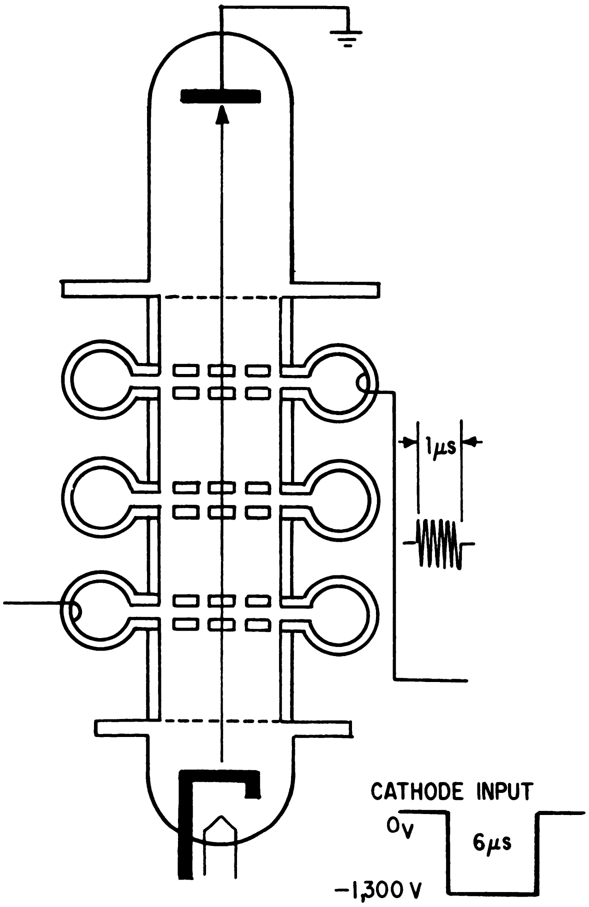

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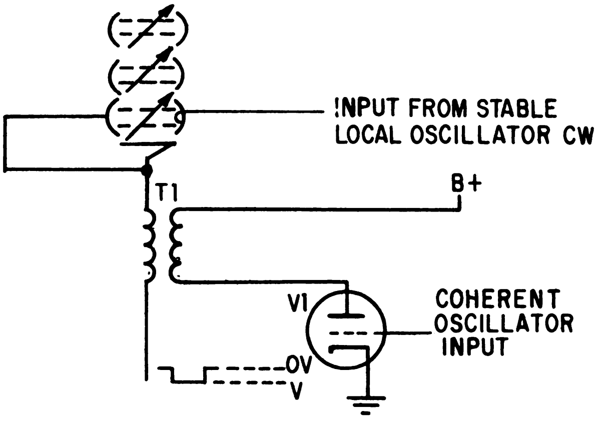
Figure 7-17.—Three-cavity klystron.

periods of time. In a moving target indicator (MTI) system, the stable local oscillator is continuously varied by an AFC system to track with the magnetron. A lock (transmitter) pulse is supplied to the coherent oscillator at the beginning of each output pulse to provide a reference phase for the echo returns.

The pulse to pulse frequency of the magnetron is subject to considerable variation for which the AFC system cannot compensate instaneously. As a result, pulse to pulse phase differences occur because of magnetron frequency changes; these changes limit fixed target cancellation. The klystron, on the other hand, is simply a power amplifier and has no influence on the frequency determining system. A reference oscillator (stable local oscillator) is maintained at an almost constant frequency and is effectively isolated from the output stage by intermediate amplifiers. The reference oscillator output which is the input to the klystron amplifier is mixed with the coherent oscillator output to produce the desired output frequency.

Because the frequency determining oscillators operate at a low level, both can be made extremely stable and the pulse to pulse frequency variations are almost negligible. No AFC is needed in such a system and the pulse to pulse phase variations of the transmitter output stages are limited by providing a modulator pulse having a suitably flat topped portion. The fixed target cancellation of an associated MTI system is considerably improved by the low pulse to pulse phase variations, and the radar transmitter is no longer considered the limiting factor in the MTI performance of a radar system.

The disadvantages of the klystron are chiefly the circuit complexities of the transmitter. A series of amplifiers are inserted between the frequency determining oscillators and the power amplifier klystron. These stages must be individually tuned when the operating frequency is changed. Most of these stages are pulsed, and synchronizing problems arise. Power supply requirements are also increased. The bulk of the equipment required in a high power klystron radar system limits the mobility of such a system, and the radar installation employing klystrons is either a fixed station or one of limited mobility. Regardless of the disadvantages, the klystron system complexity and bulk are justified in that they insure consistent MTI performance which excels that possible with magnetrons.


INPUT FROM STABLE LOCAL OSCILLATOR CW
T1
B+
V1
COHERENT OSCILLATOR INPUT
0V
V

AQ. 90
Figure 7-18.—Simplified klystron mixer circuit.

KLYSTRON MIXER TUBE

Another utilization of the multicavity klystron, other than a power amplifier, is that of a mixer. The klystron is used as a mixer tube primarily when the power amplifier klystron is used in the transmitting system. The mixer is used to mix the stable local oscillator signal and the coherent oscillator signal to produce the transmitter frequency. A typical klystron mixer circuit is shown in figure 7-18 and is referred to as the synchrodyne tube.

The synchrodyne tube mixes the coherent oscillator output with the stable local oscillator output to produce pulsed energy of the proper frequency for application to the first cavity of the power output klystron in the transmitter. The synchrodyne tube is a three-cavity, low power klystron. The mixing procedure occurs in the flow of electrons in the drift tube from the cathode to the collector. Tuning of the cavities is accomplished by three tuning knobs (one for each cavity) which determine the resonant frequency of each cavity. These tuning knobs are accessible from the top of the tube.

The drive pulses applied to the cathode are negative; they are remodulated by the pulses of coherent oscillator energy fed into modulation transformer T1 by driver tube V1. The drive pulse applied to the cathode causes beam current to flow for the entire period. But the RF energy is applied for only a period during the drive pulse, and the mixing process is in operation during this time. The output of the stable local oscillator is applied to the first cavity of the synchrodyne tube continuously. The second and third (output) cavities of the synchrodyne tube klystron are so tuned that they are resonant only to a frequency that is the difference between the stable local oscillator and coherent oscillator frequencies. Accordingly, the synchrodyne has an output only during the intervals when the coherent oscillator pulses are applied to the synchrodyne tube's klystron cathode.

The mixing process is accomplished in the density modulated electron beam in the synchrodyne. The beam is modulated by the coherent oscillator energy and the first cavity is tuned to the frequency of the stable local oscillator. The second and third cavities are tuned to the difference between the coherent oscillator and the stable local oscillator frequencies. The collector of the synchrodyne tube is grounded since the beam voltage is applied as a negative pulse on the cathode. Figure 7-19 illustrates how the synchrodyne is used as a mixer tube in conjunction with an intermediate stage.

POWER SUPPLY

The high voltage power supply is not classified as an RF component. However, it is a necessary component in the radar transmitter's operation. There are various types and circuits arrangements in use in present day aviation fire control radar transmitters. The high voltage power supply illustrated in figure 7-20 is a simplified schematic diagram of the pulse forming network high voltage power supply circuit. It is a typical high voltage power supply and does not pertain to any particular equipment, but with a thorough understanding of its operation the technician should have little trouble in analyzing other types found in the various fire control radar equipments.

The pulse forming network high voltage power supply may be located in the transmitter unit proper or in a separate unit of the radar set known as a modulator. In sets utilizing a modulator many of the power supplies necessary for proper operation of the complete radar set are contained in this unit. This includes the regulated and unregulated low voltage supplies, the indicator high voltage supply, and the pulse forming network high voltage supply.

The pulse forming network high voltage power supply illustrated in figure 7-20 is a voltage doubling circuit whose output voltage is used to charge the pulse forming network, which in turn fires the magnetron.

V1 and V2 are rectifier tubes connected as a voltage doubler circuit. C1 and C2 are the voltage doubler capacitors across which the output doubled voltage is obtained. R66 through R75 are tied across the output and serve as bleeder resistors. The solenoid of K1 tied between the plate and ground of V2 is an overload relay. K1 is connected so as to break one of the a-c input leads to the primary of the high voltage transformer, T2, if a temporary overload or a short circuit occurs in any circuit fed by the power supply. It can be seen, from figure 7-20, that if for some reason the current through the solenoid of K1 increases to the point where it will energize, the shorting bar of K1 will break the connection between contacts 1 and 2, opening one line of the input a. c. to T2. R3 is a relay coil shunt resistor, a protective device used to limit the current through the relay coil and protect the relay. T2 is the high voltage transformer for the voltage doubler

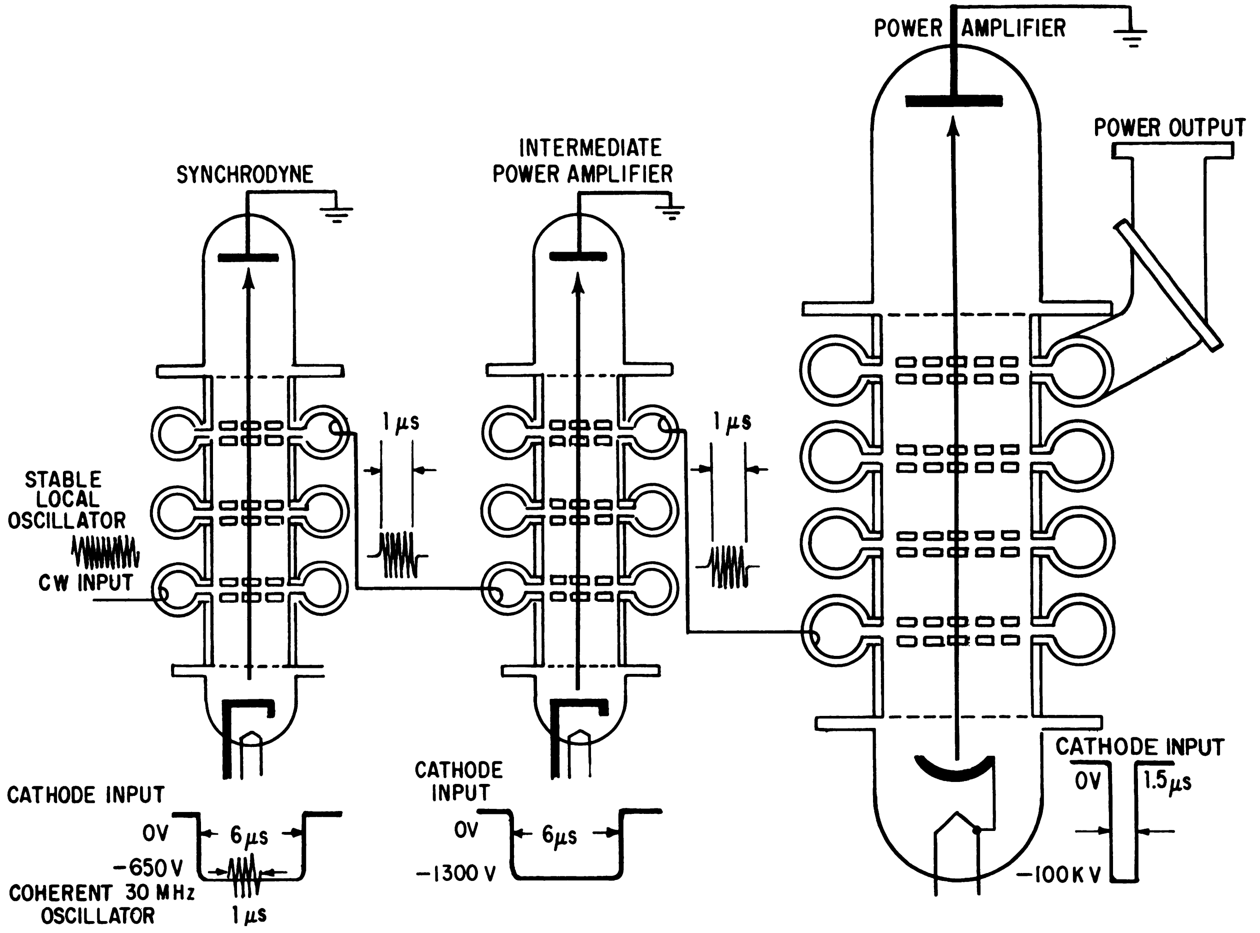


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Figure 7-19. – Multicavity klystron stages.

circuit. The turns ratio of T2 is approximately 1:17.5 and its secondary is tied in to complete the voltage doubler circuit. Pin No. 2 of the primary of T2 is tied back through the contact of K1 and S4 to the arm of the variable autotransformer TF6 and pin No. 1 is directly tied back to one side of the 115-volt a-c input.

S4 is a safety switch to provide protection to personnel handling the unit housing the power supply (modulator). This switch springs open when the cover to the unit is removed and opens the variable autotransformer brush circuit, breaking one side of the input to T2.

TF6 is a variable autotransformer used as a means of controlling the magnetron current. TF6 is usually mounted separately from the rest of the power supply and is the Hi-Lo magnetron current adjustment made by the operator to obtain the rated value of magnetron current as indicated by the magnetron current meter on the control unit. One side of this transformer is tied directly to one side of the input a.c. (common). The other side is connected to a taped autotransformer, T5, through relay K2, or K2 and K3, depending on the power required on the magnetron.

It can be seen that by varying the contact arm of TF6, the amplitude of the a.c. to the primary of T2 will vary. This in turn will determine the amount of voltage supplied to the PFN. The amount of charge on the PFN will determine how much current is passed by the magnetron. The technician should bear in mind that the meter on the control unit is connected into the magnetron cathode circuit when the meter selector switch is on MagCur position and is a direct reading of magnetron current.

Relays K2 and K3 may be referred to as a "coarse" control of the high voltage output and used to vary the power out of the magnetron

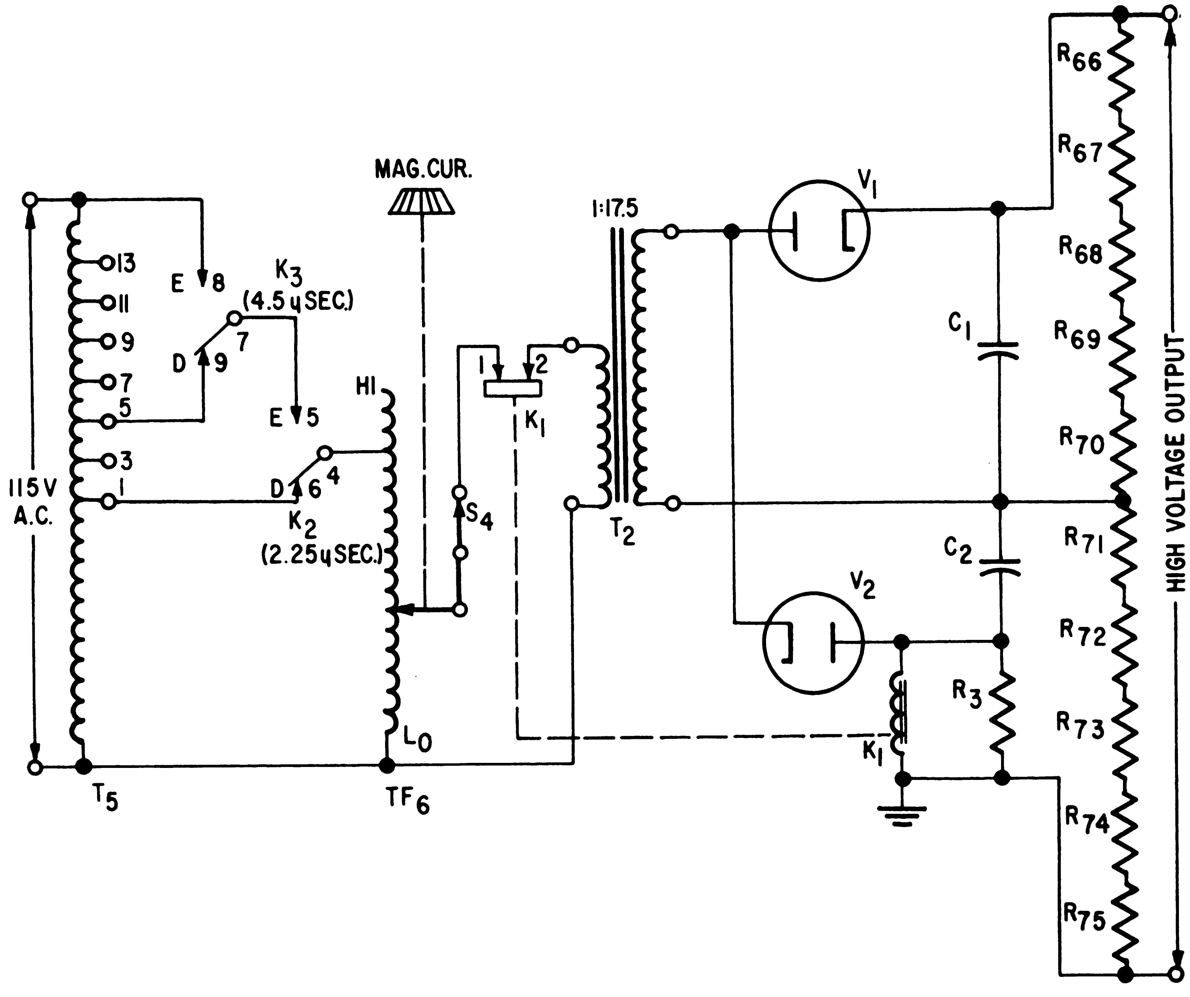

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Figure 7-20.–PFN high voltage power supply.

when changing the range of operation of the equipment. On short range, less power is needed; therefore less charge is needed on the PFN to drive the magnetron.

The variable arm of TF6 gives a "fine" control over the high voltage output for setting the rated magnetron current.

The tapped autotransformer, T5, will have 115 volts a. c. across it after a set time delay. This time delay is to enable the other circuit elements to reach operating condition prior to applying the high voltage. It should be remembered that the power supply circuits discussed are typical and may differ with various equipments.

TRANSMITTER CIRCUIT ANALYSIS

In the previous sections of this chapter the functional operation of a typical radar transmitter, the various RF components, and the required high voltage power supply were discussed. The following discussion will show the circuit tie-in and relation of these components to make up a typical aviation fire control radar transmitting system.

OPERATION

Refer to figure 7-21, a simplified schematic of the trigger shaper, cathode follower, and transmitter pulse circuits.

V1, the trigger shaper, (a blocking oscillator), is maintained inoperative (cut off) by the fixed bias from the voltage divider in its cathode circuit, (R2 and R3). The positive input pulse from the synchronizer overcomes this fixed bias and trigger the blocking oscillator, V1, into conduction. The blocking oscillator produces a single output pulse which is fed to the cathode follower V2. The output of V2, taken from the cathode, is coupled to the grid of V3, the pulse switch tube. (The series coil, L1, is used as an isolating inductance for V2 during the period of time when V3 is ionized.)

Prior to the trigger on V3's control grid, the switch tube, a thyratron, is de-ionized and nonconducting because the PFN voltage is of insufficient amplitude to cause conduction. Even with zero bias, V3 requires a positive input pulse on the control grid to fire and start conduction.

During this de-ionized (cutoff) period, the PFN (Z1) is charged to approximately twice the output voltage of the high voltage power supply. This may be explained as follows: The charging diode, V4, with a high positive voltage on its plate, will conduct and draw electrons off the top plates of the capacitors in the PFN. The resultant current flow through L3 develops a strong magnetic field around the coil. The power supply will continue to charge Z1 until the voltage of the PFN is equal to the voltage on the diode's plate.

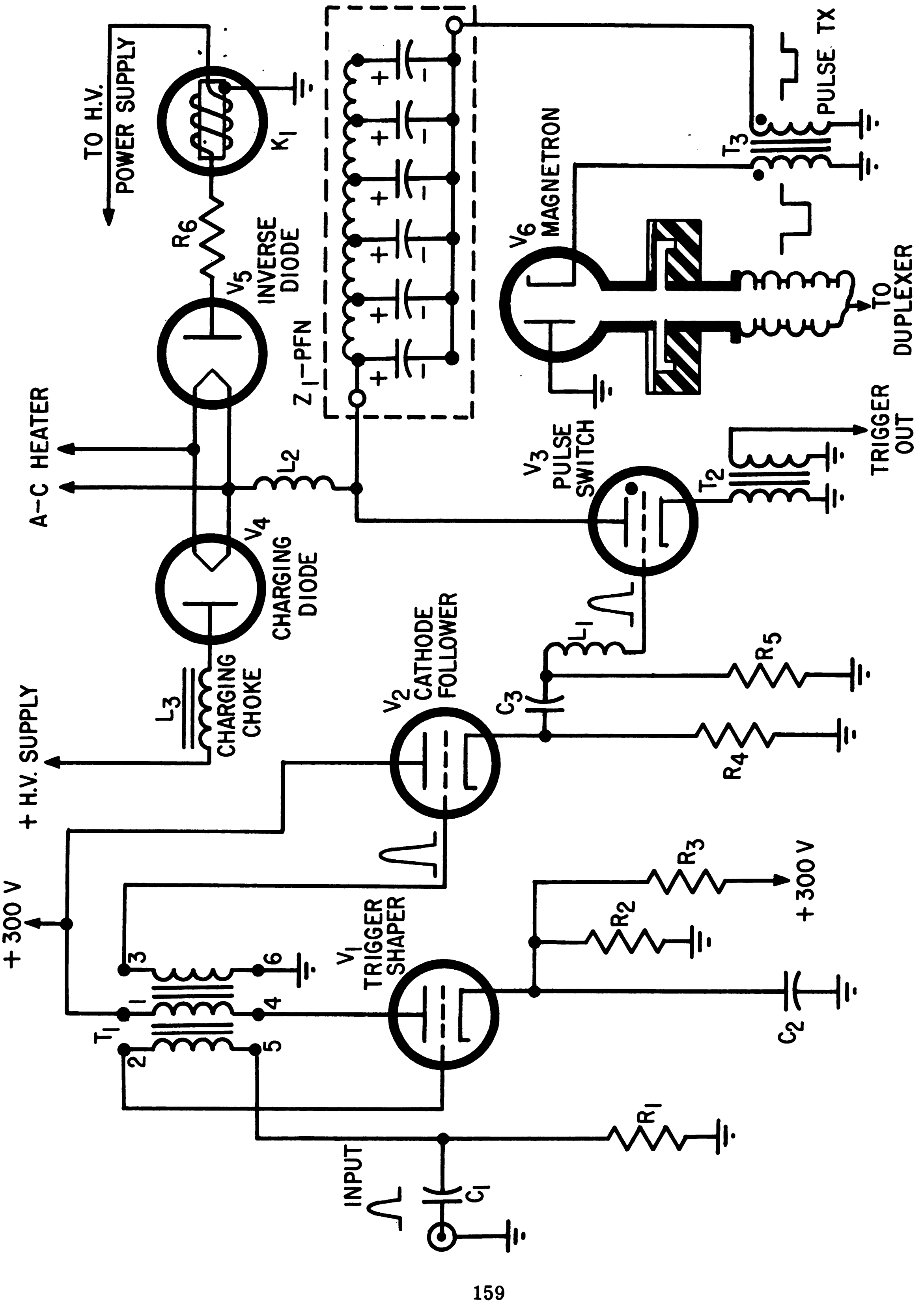
When current flow tends to cease, the field around L3 collapses keeping current flowing in the same direction and removing additional electrons from the top plates of the capacitors in the PFN. The inductor L3 is sufficiently large to raise the charge on the PFN to almost twice the E_{bb} of the diode. Since V4's cathode is more positive than its plate, the PFN will remain at this increased voltage until triggered. This method of charging a PFN is normally called d-c resonance charging with a diode, and is most frequently used in present aviation fire control radar sets.

With the PFN thus charged, the effect of the input trigger to V3, the switch tube, may be analyzed. The positive trigger on the control grid of V3 is sufficient to fire the thyratron. With the thyratron conducting heavily, the PFN is effectively connected across the primary of the pulse transformer. The PFN voltage acts as the source of attraction for current through the pulse switch tube, which will remain ionized until removal of its plate voltage. The PFN may now discharge, pulsing the magnetron for a period of time determined by the PFN. When the PFN is completely discharged, V3 will again de-ionize and the PFN is free to recharge.

The state of charge on the PFN at the end of pulse time is dependent upon the relationship of the discharge circuit impedance to the characteristic impedance of the PFN. To completely discharge the PFN the discharge circuit impedance must equal the characteristic impedance of the PFN. If the discharge circuit impedance (which is primarily that offered by T3) is not equal to the characteristic impedance of the PFN, a reversed charge on the PFN may result. This reversed voltage on Z1 (PFN) at the end of pulse time can cause Z1 to be charged to a higher voltage than twice the power supply voltage. Subsequent pulses would increase the reversed voltage and Z1 would be charged higher with each additional pulse. The effects would be accumulative until breakdown of components due to higher voltage would occur. This possibility of high reverse voltage and component breakdown is eliminated in the circuit illustrated in figure 7-21 by the action of V5, the inverse diode, and K1, a heat sensitive relay. If a mismatch occurred and reversed voltage tended to build up in Z1, V5 would conduct, allowing removal of the reversed PFN charge through R6 and the heater winding of the thermal relay, K1, to ground. The current through the heater winding of K1 would be high enough to cause the bimetal strip to bend away from the ground contact, operating a protective relay. This relay opens the primary circuit of the high voltage power transformer, thus protecting the transmitter components from a possible high voltage breakdown.

The purpose of L2 in the circuit is to isolate V3 from the power supply during pulse time.

The amplitude of the output pulse to the transmitter oscillator (magnetron) is controlled by the turns ratio of T3, the pulse transformer. The voltage across the primary of T3 is usually one-half the charge on the PFN at pulse time as the impedance offered by T3's primary is equal to the characteristic impedance of Z1. Therefore, at pulse time one-half of Z1's charge is applied across the primary impedance of T3, the other half appearing across the characteristic impedance of the PFN. This pulse is stepped up across T3 and applied to the cathode circuit of the magnetron, driving the magnetron into operation as previously discussed. The high powered output RF energy is coupled into



AQ. 93

Figure 7-21.—Trigger shaper, cathode follower, and transmitter pulse circuits.

the waveguide in the form of RF pulses whose duration is controlled by the PFN. Their amplitude is controlled by the setting of the autotransformer in the high voltage power supply.

The pulses of high powered RF energy are propagated through the waveguide into the duplexer assembly illustrated in figure 7-22.

The TR tube and the ATR tube are placed so that the tubes ionize and the spark gaps arc over during transmit time, and thus reflect a short at the walls of the main waveguide. This causes the waveguide to appear continuous to the transmitted pulse and allows the transfer of maximum energy from the transmitter to the antenna.

The purpose of the keep-alive voltage and TR and ATR tubes was discussed previously and serves the same purpose in the duplexer assembly illustrated in figure 7-22.

A small portion of the transmitted energy is taken from the main waveguide by the AFC (automatic frequency control) cavity and used by the AFC circuits to maintain a constant IF (intermediate frequency) during the receive cycle. The purpose and the operation of the AFC circuits are covered in chapter 9 of this manual, entitled Radar Receivers.

The circuits and components discussed are typical of the ones found throughout aviation fire control radar transmitters. The technician should bear in mind that no particular system was discussed; but a thorough understanding of the material covered will greatly aid in understanding the various radar transmitters he may be required to maintain.

MICROWAVE SINGLE-SIDEBAND TECHNIQUES

The AN/APA-127 and -128 equipments use a magic-T as a source of a pseudo Doppler signal. In this application, it is actually used as a single-sideband generator or a frequency translator; that is, it translates a signal up the spectrum by the amount of the modulating signal frequency. In this way, the frequency of a microwave signal can be apparently changed over a reasonable range by changing the modulating frequency.

The following discussion describes the theory, using vector relationships, of a standard tube type single-sideband generator and, from that, develops the theory of operation of microwave single-sideband generators.

BALANCED MODULATOR

A balanced modulator can take the form of a class C tuned amplifier. (See fig. 7-23.) The RF carrier signal is fed to the grids of V1 and V2 in a push-pull manner (180° out of phase) while, at the same time, the audio modulating signals at each grid are in phase. The plates are connected in parallel to a common load impedance.

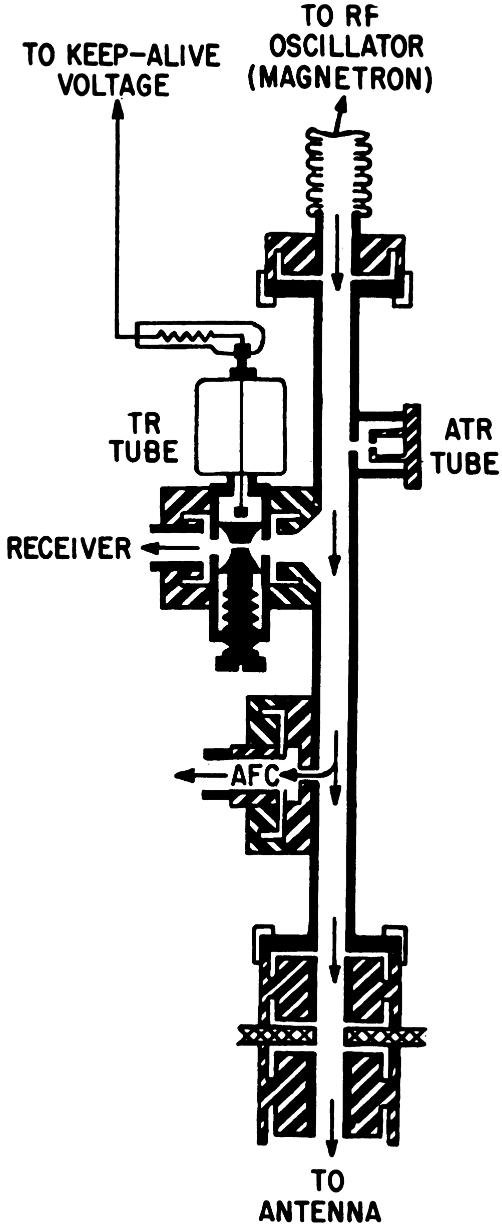
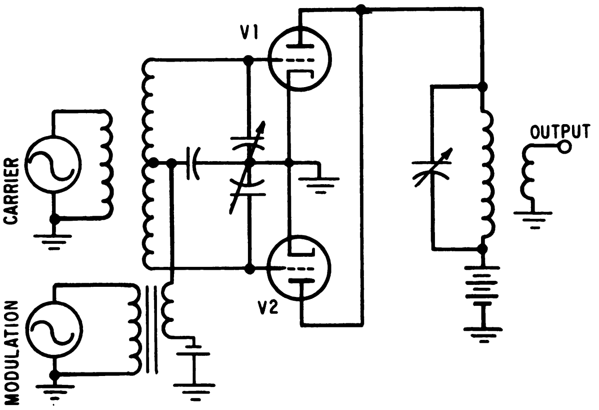


Figure 7-22.–Duplexer assembly (transmit cycle). AQ.94



AQ. 95

Figure 7-23. –Balanced modulator.

If the circuit is balanced and no modulation is applied, it is apparent that there will be no output. The carrier voltage developed at the plate of each tube cancels that developed at the other. When modulation is applied, however, each tube acts as a grid modulated class C amplifier; and there is a resultant voltage output. The carrier signals still cancel, but the phase of the sideband signals is such that they reinforce each other.

The signal and vector relationships are shown in figure 7-24. The sum of the three vectors C_{1a}, L_{1a} and U_{1a} represents the voltage at the plate of V1 while the audio modulating voltage cycle is passing through the 30° point. Other vector diagrams in figure 7-24 illustrate conditions at the plates of V1 and V2 and at the output, when the audio modulating voltage cycle is passing through 90°, 180°, and 300° points.

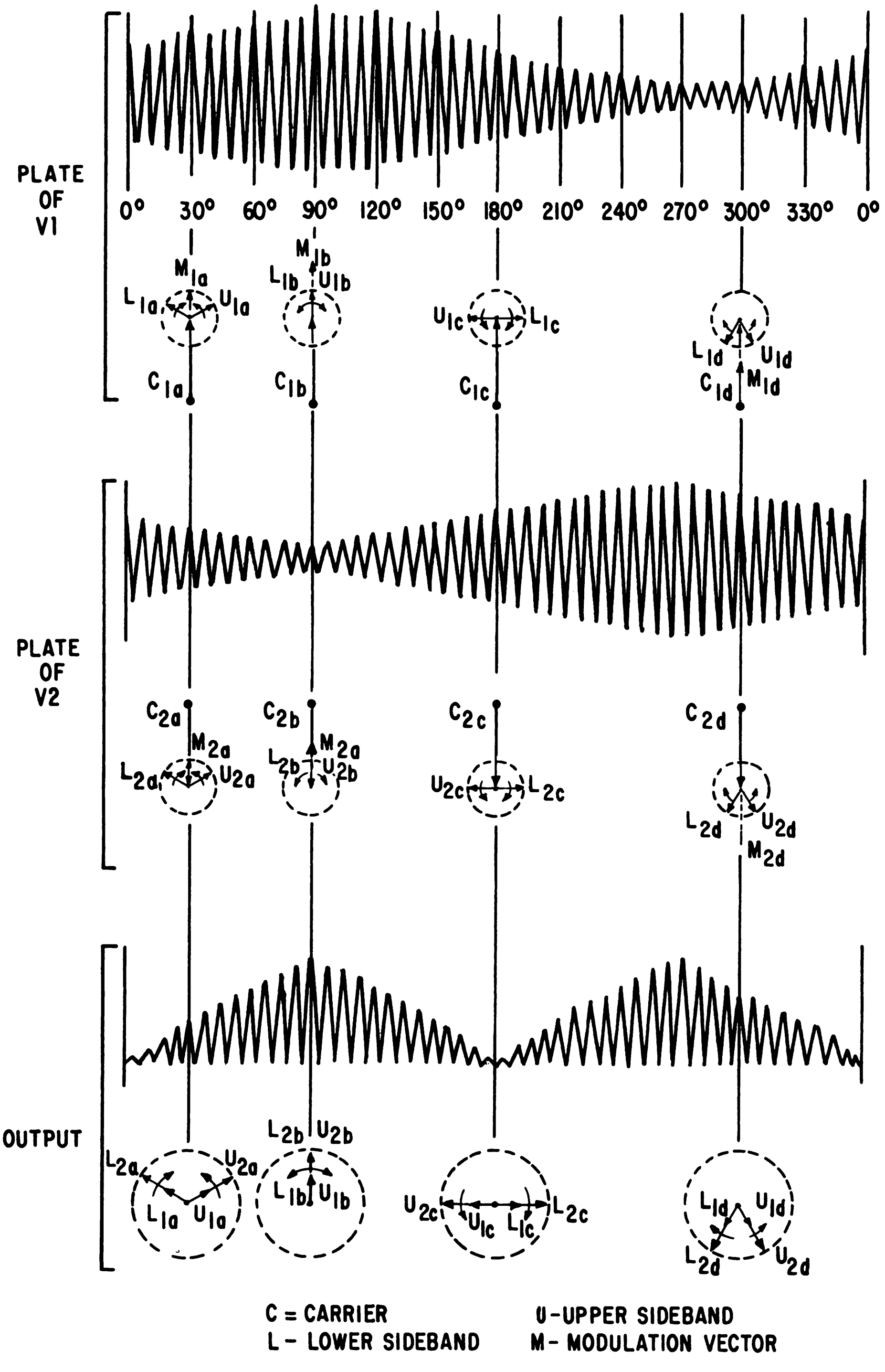
The C vectors appear to be fixed because the carrier frequency is used as the reference. However, the upper and lower sideband vectors, U and L, appear to rotate. The upper sideband frequency is higher than the carrier; consequently, the U vectors are constantly gaining in phase angle (rotating counterclockwise). The lower frequency L vectors are constantly losing in phase angle and, therefore, appear to rotate clockwise. The angular rate of both the U and L vectors is equal to $2 \pi F_m$ because both sidebands differ in frequency from the carrier frequency by an amount equal to the modulating frequency F_m.

It is apparent in figure 7-24 that the angle between the U and C vectors is always equal to the angle between the L and C vectors. Therefore, vectorial addition of the U and L vectors always results in an M vector that is parallel to the C vector. The length and polarity of the M vector will depend upon the positions of U and L. If U and L are in the upper semicircle part of their rotation, the M vector will point toward the top of the page. If U and L are in the lower semicircle part of their rotation, the M vector will point toward the bottom of the page. The M vector does not appear to rotate; therefore, it is of the same frequency as the C vector.

It should also be noted that the amplitude and polarity of the M vector correspond to the amplitude and polarity of the modulating signal. This is illustrated by vectors M_{1a}, M_{1b}, and M_{1d} in figure 7-24. There is no M_{1c} vector because, at that instant (180° on the audio cycle), upper and lower sideband signals are 180° out of phase.

When the M and C vectors associated with the plate of V1 are added vectorially, their sum represents an RF signal whose amplitude varies at an audio rate (amplitude modulated). Notice that the C_{2a} vector is 180° out of phase with the C_{1a} vector, while the M_{2a} vector is in phase with the M_{1a} vector. This occurs because the grids of V1 and V2 are modulated by the same audio voltage. Vectorially adding the C and M vectors associated with the plate of V2 also results in an RF signal whose amplitude varies at an audio rate (AM).

The balanced modulator output signal results from adding all of the vectors associated with the plate of V1 to all of the vectors associated with the plate of V2. It is apparent that the C vectors cancel. The U vectors are always in phase and therefore add directly. The L vectors also add directly. The result is two sideband signals, U and L. Since the vectors remain referenced to the carrier frequency, the U vectors continue to rotate counterclockwise and the L vectors continue to rotate clockwise. The double-sideband suppressed carrier output RF signal results from vectorially adding the output U and L vectors. As seen in figure 7-24, it reaches a peak at the 90° and 270° points on the audio cycle and undergoes a phase reversal at the 0° and 180° points.



AQ. 96

Figure 7-24. –Balanced modulator signal and vector relationships.

SINGLE-SIDEBAND GENERATORS

A typical single-sideband generator (fig. 7-25) uses two balanced modulator circuits. The phases of the carriers and sidebands are adjusted so that the carriers and one sideband cancel. The remaining sideband is reinforced.

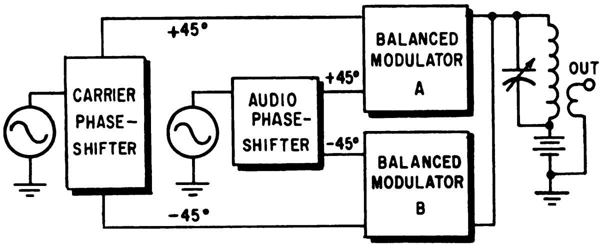


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Figure 7-25. -A typical phasing method of generating single sideband.

The RF phase shifter causes the carrier input to modulator B to lag the carrier input to modulator A by 90°. Consequently, the carrier output of the modulator B will lag the carrier output of modulator A by 90° as shown in figure 7-26. The vectors present at the plates of V1 and V2 are shown in figure 7-26 as modulator A output vectors. Modulator B output vectors are those present at the plates of V3 and V4.

The audio modulating frequency and, consequently, the sideband vectors, are also phase shifted 90°. In figure 7-26, the U and L vectors have all been retarded 90°. To aid in explaining how this was done, dotted vectors U_x and L_x were drawn as they would have appeared if the modulating voltage had not been phase shifted. The direction of rotation of each sideband vector must be considered when determining the 90° lag. Hence, U_{3a} lags U_x by 90° and L_{3a} lags L_x by 90°.

The output of modulator A is vectorially added to the output of modulator B in a common output impedance. It is apparent from figure 7-26 that all C vectors and all U vectors will cancel, but all L vectors will add together. The resultant output voltage will be a single frequency-the lower sideband. Of course, it will still appear to rotate clockwise, since the reference is the carrier frequency.

The upper sideband can be obtained by reversing the phase of either the carrier inputs or the modulation inputs. Figure 7-27 shows the signal and vector relationships with the audio modulation input phases to the two modulators reversed. The carriers still cancel; but the upper sidebands now add together and the lower sidebands cancel.

Magic-T Type

A microwave equivalent in the form of a magic-T type single-sideband generator is shown in figure 7-28. The magic-T, which is a combination H-plane and E-plane junction, is also discussed in chapter 6 of this manual. The RF carrier enters the magic-T through the H arm. At the junction, the energy divides evenly: half of the energy goes down each arm toward a crystal. (No energy can propagate directly from the input H arm to the output E arm.) Arm No. 2 is 1/8 wavelength longer than arm No. 1; consequently, the carrier wave arriving at crystal No. 2 will lag, by 45°, the carrier wave arriving at crystal No. 1.

Theoretically, the crystal diodes are so matched to the waveguide arm that they will absorb all of the carrier energy when there is no modulation applied to them. This is, theoretically, how cancellation of the carrier is achieved.

When modulation is applied, the impedance of the diodes will be changed; neither of the diodes will be a perfect match. Therefore, a portion of the energy traveling down each arm will go past the diode and be reflected from the short circuit at the end of the arm. This is actually amplitude modulation. After being reflected, the energy goes back up each arm to the junction.

The reflected AM wave traveling up arm No. 2 to the junction must go an additional 1/8 wavelength farther than the reflected AM wave traveling up arm No. 1. Therefore, their carriers would be 90° out of phase because of the total 1/4 wavelength difference in the length of the path traveled. In addition, the sidebands will be shifted 90° because the modulating signals applied to the diodes are 90° out of phase. Consequently, the sideband vectors of the signals reflected from arm No. 1 and arm No. 2, shown in figure 7-29, are in exactly the same relationship as the sideband vectors (fig. 7-26) at the output of balanced modulators A and B.

Keep in mind that figure 7-29 is the theoretical case where the carrier was eliminated due to the characteristics of the diodes. Also, in order to have an output on the E arm, the reflected signals arriving at the junction from arms Nos. 1 and 2 must be 180° out of phase. In other words, a difference in potential must be developed across the E arm causing the

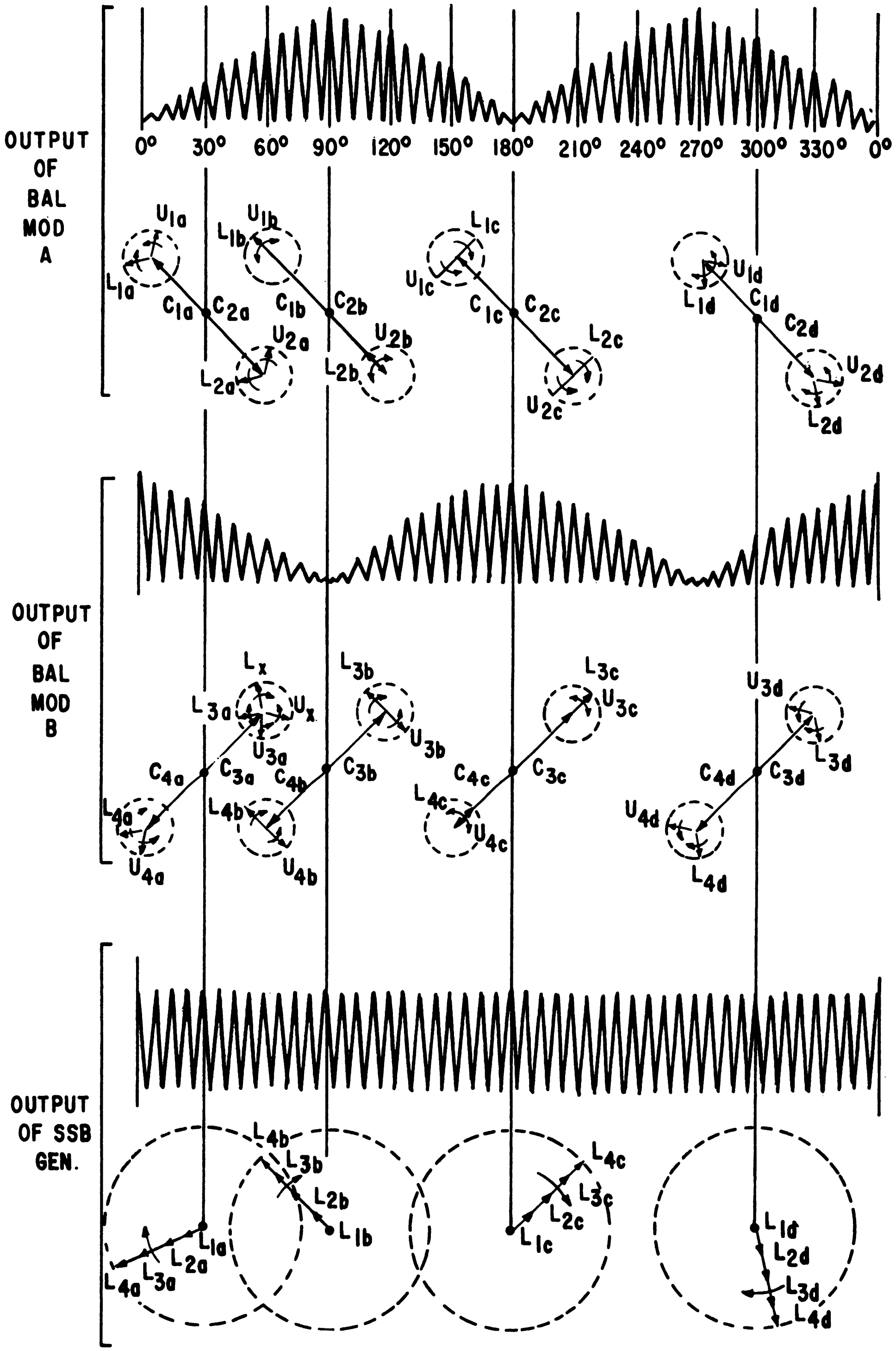

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Figure 7-26. –Single-sideband generator signal and vector relationships.

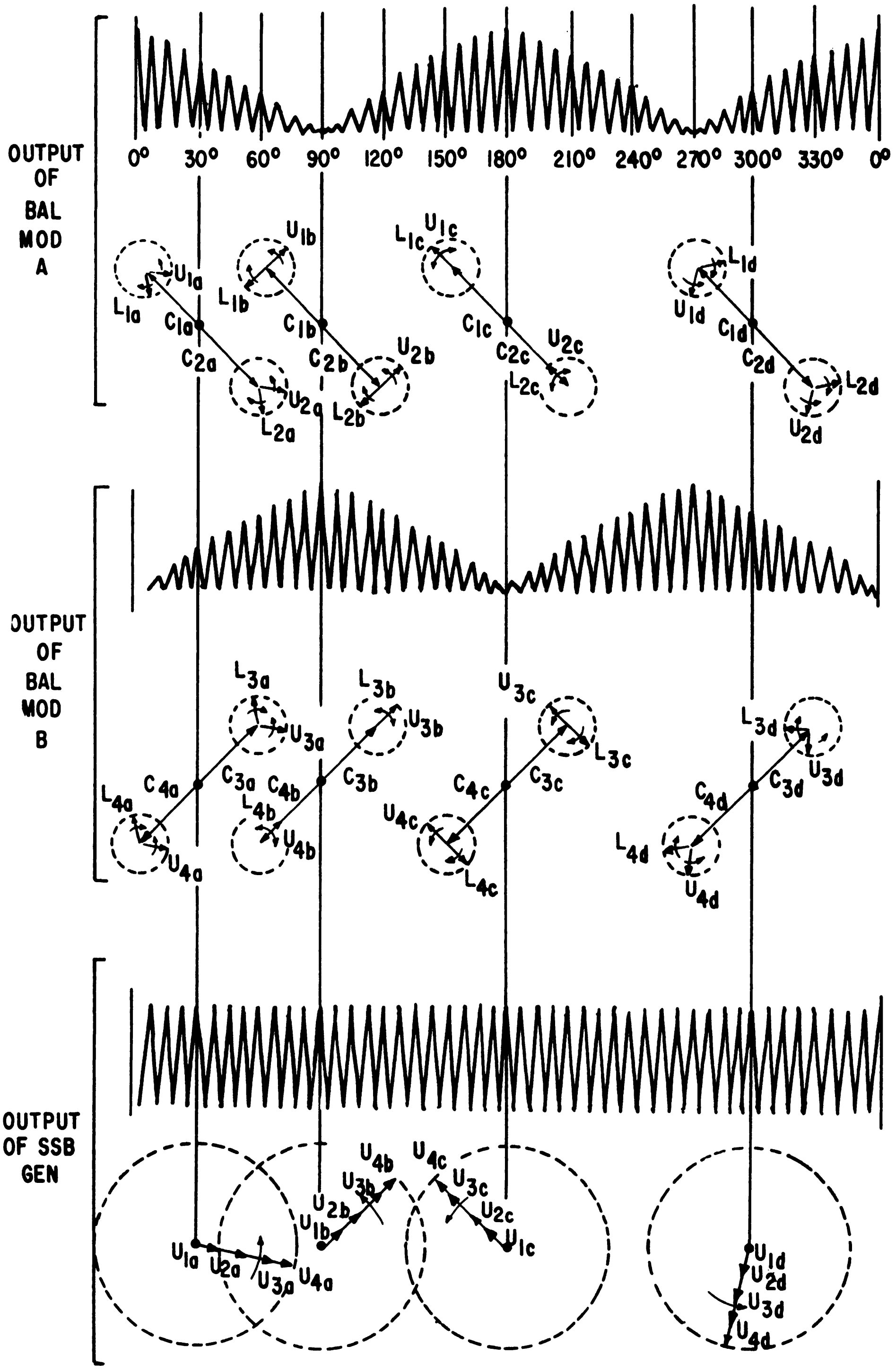

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Figure 7-27. -Single-sideband generator signal and vector relationships. (Modulation signal connections are reversed in relation to figure 7-26.)

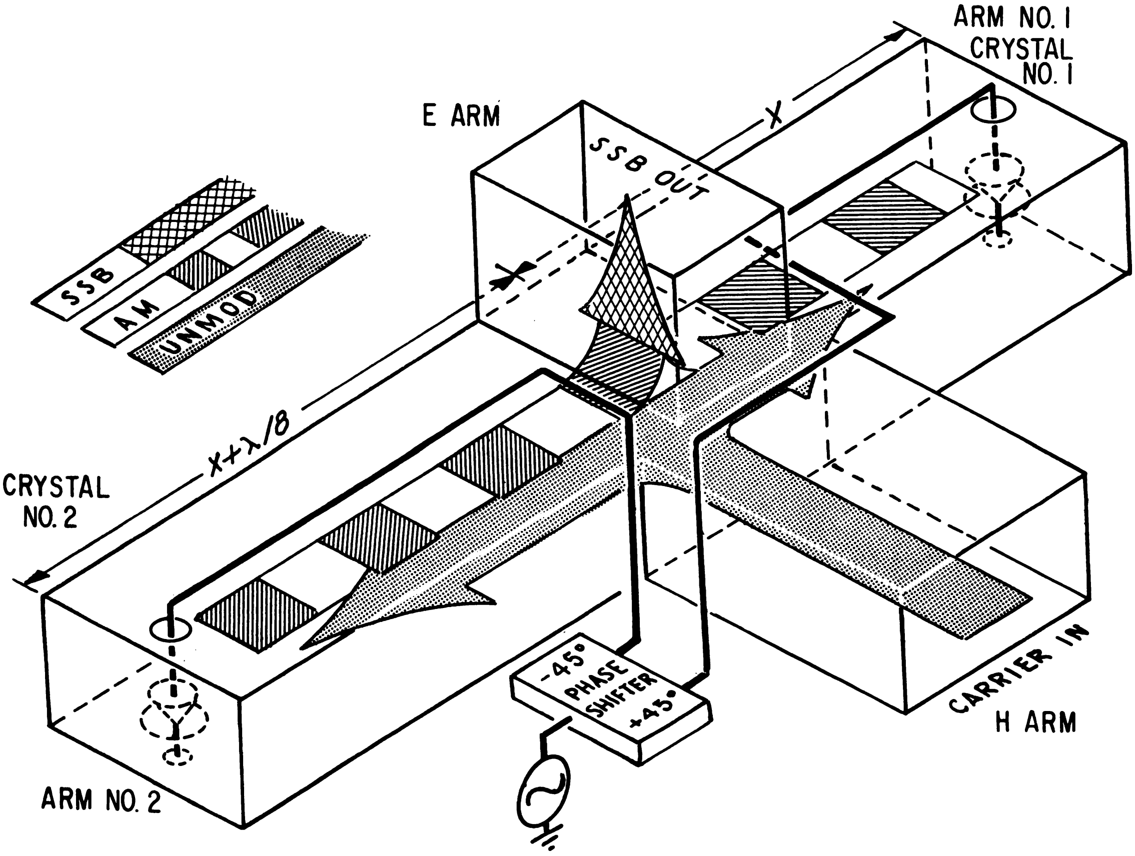

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Figure 7-28. –Magic-T type single sideband generator.

lower sideband to be blocked and the upper sideband to become the output.

In a more practical case, shown in figure 7-30, the carrier is not entirely eliminated by the diodes. To determine how much of the carrier will go out the E arm in this example, the carrier vectors are broken down into their x and y components. Since x components are 180° out of phase, they will add and pass out the E arm along the upper sideband.

Actually, although it is not shown in figure 7-30, a little of the lower sideband will also pass out the E arm because the path lengths are not perfect.

Ring Type

Another microwave equivalent in the form of a ring type single-sideband generator is shown in figure 7-31. This type is used in the AN/APN-120 electronic altimeter. In that application it is called a frequency translator.

Refer to figure 7-31 and examine the dimensions of the ring. Energy fed into the ring on arm No. 2 will divide equally between arms No. 1 and No. 3. No energy can go directly out the output arm No. 4 because energy arriving at that junction directly from the input, via the two paths, will be 180° out of phase. Similarly, energy reflected from arm No. 1 can divide between input arm No. 2 and output arm No. 4 but cannot enter arm No. 3. Also, energy reflected from arm No. 3 can divide between input arm No. 2 and output arm No. 4 but cannot enter arm No. 1.

Consider a case where no modulation is applied to the crystals, and energy is fed into the ring at arm No. 2. Due to the distances traveled, energy arriving at output arm No. 4 (which has reflected from the crystal in arm

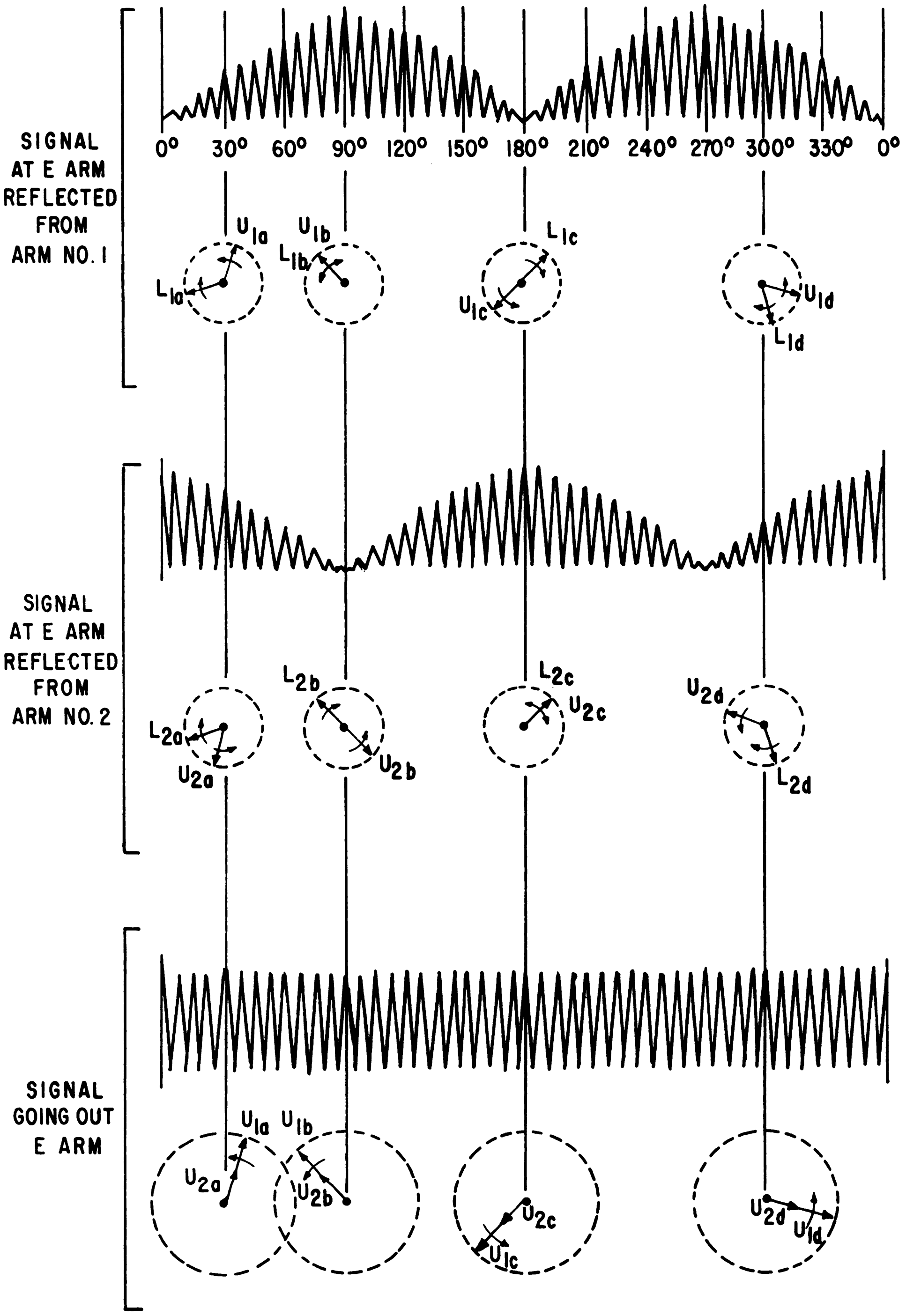

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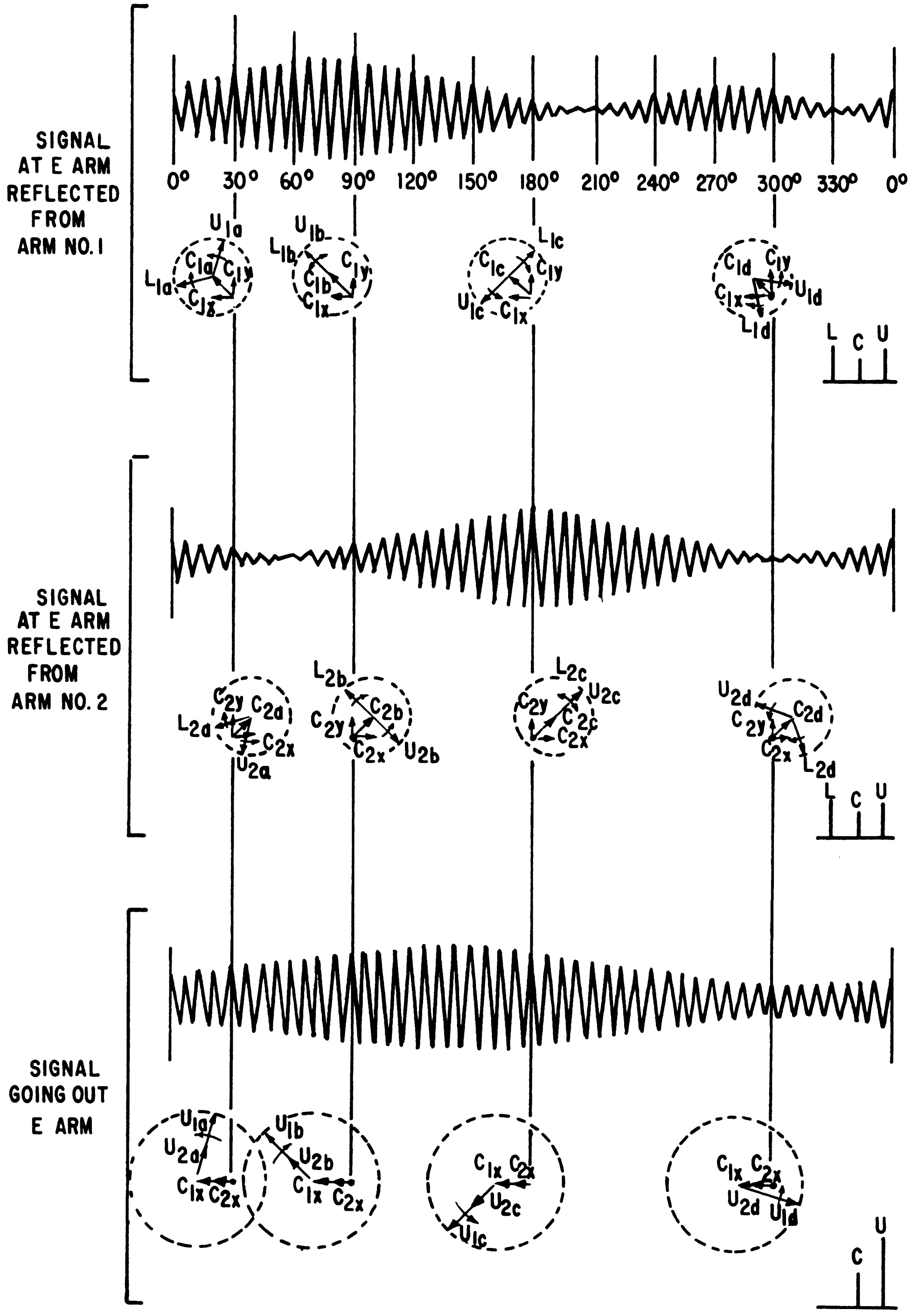
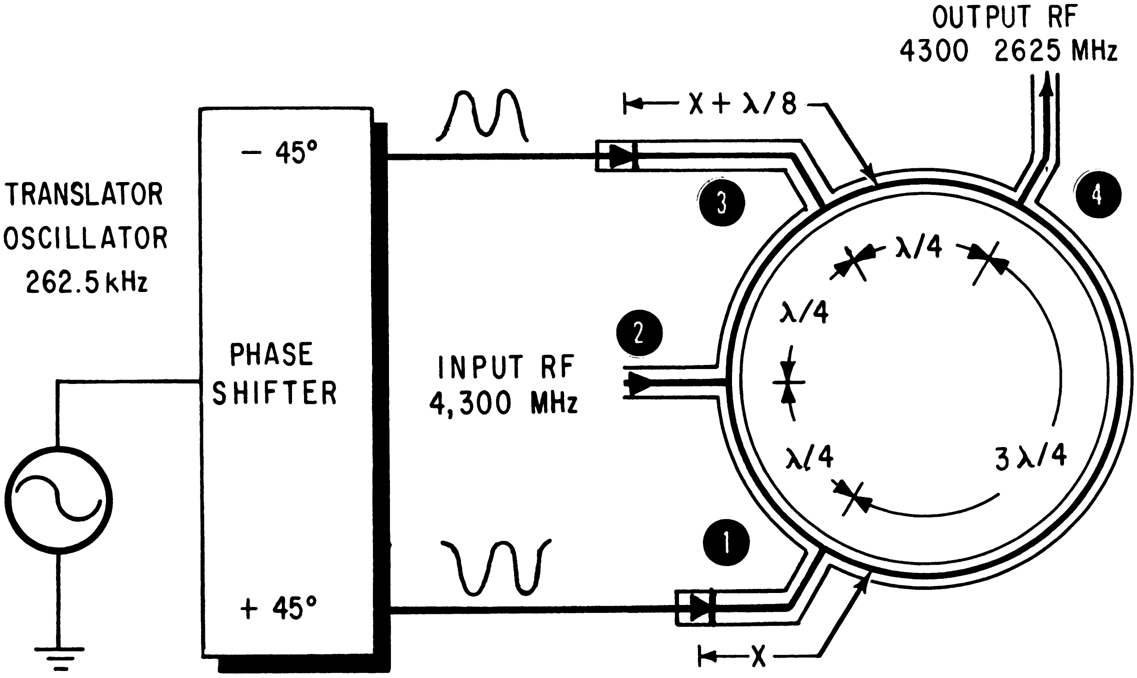
Figure 7-29. -Magic-T type single-sideband generator. Theoretical signal and vector relationships.


SIGNAL AT E ARM REFLECTED FROM ARM NO. 1
0° 30° 60° 90° 120° 150° 180° 210° 240° 270° 300° 330° 0°
U_{1a} L_{1a} C_{1a} C_{1y} C_{1x}
U_{1b} L_{1b} C_{1b} C_{1y} C_{1x}
L_{1c} C_{1c} C_{1y} U_{1c} C_{1x}
C_{1d} C_{1y} C_{1x} U_{1d} L_{1d}
L C U
SIGNAL AT E ARM REFLECTED FROM ARM NO. 2
C_{2y} C_{2d} L_{2d} C_{2x} U_{2a}
L_{2b} C_{2b} C_{2y} C_{2x} U_{2b}
L_{2c} C_{2y} U_{2c} C_{2c} C_{2x}
U_{2d} C_{2y} C_{2d} C_{2x} L_{2d}
L C U
SIGNAL GOING OUT E ARM
U_{1a} U_{2a} C_{1x} C_{2x}
U_{1b} U_{2b} C_{1x} C_{2x}
C_{1x} C_{2x} U_{2c} U_{1c}
C_{1x} C_{2x} U_{2d} U_{1d}
C U

AQ. 102

Figure 7-30. –Magic-T type single-sideband generator. More practical signal and vector relationships.



AQ. 103

Figure 7-31.–Ring type single-sideband generator.

No. 1) will lag, by 90°, the energy reflected from the crystal in arm No. 3; that is, energy arriving at arm No. 4 via arm No. 1 has traveled 1/4 wavelength farther. Theoretically, when no modulation is applied to the crystals, all energy should be absorbed by the crystals because they provide a perfect impedance match and no energy would be reflected from arms Nos. 1 and 3. Actually, however, some carrier energy is reflected. (In fact, vector orientation will be more easily understood if this fact is recognized.) Therefore, the carrier vector for energy arriving at arm No. 4 via arm No. 3 would be oriented exactly as vectors C_{1a}, C_{1b}, C_{1c}, and C_{1d} in figure 7-27. The carrier vector for energy arriving at arm No. 4 via arm No. 1 would be oriented exactly as vectors C_{3a}, C_{3b}, C_{3c}, and C_{3d} in figure 7-27.

A change in the crystal bias, produced by applying modulation to the crystal, changes the reflection coefficient of the crystal and causes the reflected signal to be amplitude modulated. Since the modulating signal applied to the crystal in arm No. 3 lags (by 90°) the modulating signal applied to the crystal in arm No. 1, the upper and lower sideband vectors arriving at the output arm No. 4 via arm No. 3 will be oriented exactly as the sideband vectors at the end of C_{1a}, C_{1b}, C_{1c}, and C_{1d} in figure 7-27. Also, the upper and lower sideband vectors arriving at the output arm No. 4 via arm No. 1 will be oriented exactly as the sideband vectors at the end of C_{3a}, C_{3b}, C_{3c}, and C_{3d} in figure 7-27.

Disregarding all carrier vectors which point toward the bottom of the page (and their associated sideband vectors) in figure 7-27, it is obvious that all lower sideband vectors will be 180° out of phase and will cancel; and all upper sideband vectors will be in phase and add. A portion of the carrier vectors which were not eliminated by the crystal characteristics will also add. The carrier frequency is actually suppressed a little more than 20 db.

MAINTENANCE

The maintenance of aviation fire control transmitters as applied to intermediate and organizational maintenance activities may be broken down into shop, hangar, and line maintenance and component repair.

Complete maintenance and service instructions as applicable to the above levels of maintenance are covered in the appropriate sections of the aircraft Maintenance Instructions Manuals. Some equipments may also have additional Service Instruction Manuals for the particular equipment.

LINE AND HANGAR MAINTENANCE

Troubleshooting and repair at the line and hangar maintenance levels are limited to localization of trouble to a defective component, control, or associated aircraft wiring of the set. Operational and end to end tests are made using the appropriate test equipment. Alinement procedures may be included with the operational testing procedures to conserve time. Removal and installation procedures are given with a list of special tools needed.

SHOP MAINTENANCE

After the line/hangar maintenance crew has isolated the trouble to a defective major component, it is turned in to supply and a new component is received. Supply, in turn, sends the defective component to the intermediate level maintenance activity for screening and/or repair. During shop maintenance, the component is repaired and then returned to the supply system for reissue.

Component Repair

Component repair is defined as all maintenance procedures that are performed on a component after removal from the aircraft. Component failure may result from one or a combination of electrical or mechanical troubles. Any systematic approach to analyzing component failures has for a main objective the isolation of the trouble to a faulty module as quickly and as accurately as possible. To expedite the isolation of trouble, the maintenance man takes advantage of any knowledge he may have obtained from previous experience, trouble analysis reports, or recurring malfunctions. He also used, to greatest advantage, any information he can obtain quickly from a preliminary visual inspection of the troublesome component.

PRELIMINARY INSPECTION. - The preliminary inspection of a defective component is essentially a visual inspection. It includes inspecting for loose modules, broken connections, loose and broken pins, loose tubes, cracked cabinets, discolored parts, and cabinet wiring. Maintenance Instructions Manuals list in tabular form the items to be inspected and the desired condition of the items. The preliminary inspection is always performed before using the test equipment.

TROUBLE ANALYSIS PROCEDURES. - The component trouble analysis procedures are based on a set of tables which include intuitive type data based on trouble analysis reports, chronic malfunctions, and technician experience. A table is provided for each component of the system. The tables list the symptom, probable cause, and corrective action.

PULSE EXPANSION AND COMPRESSION

Within the past few years, an amazing and powerful radar technique called pulse compression (nicknamed "Chirp Radar") has been incorporated in all types of radars. Pulse compression is possibly the most significant new advance in radar techniques in many years. It can improve a radar's performance by a factor of possibly several hundred. There appears to be no limit in sight to its possibilities. It is finding use in long range search, missile control, fire control, weather observation, aircraft traffic control, mapping radars, and many more. Frequently, computers are used to display the returned target information using standard target symbols rather than displaying conventional video on a PPI type indicator. These symbols depict target position, size, type aircraft, and movement of the target. Generally, the radar is computer controlled.

ADVANTAGES

Some of the advantages which are discussed in this section are extended range with improved range resolution, height finding capabilities, immunity from ECM jamming, and an increased signal-to-noise ratio.

Extended Ranges

One important factor in any radar's maximum range is the envelope power. Envelope power is found by multiplying the pulse width times the peak power. A typical search radar has a pulse width of 2 μsec and a peak power of 2. 5 megawatts. This will produce an envelope power of 5 watts/sec. A typical pulse compression radar will have a pulse width of 10 μsec and peak power of 1 megawatt which will produce an envelope power of 10 watts/sec. Since range is partially determined by the transmitter, this will give us the possibility of an increased range over the conventional pulse radar.

Improved Range Resolution

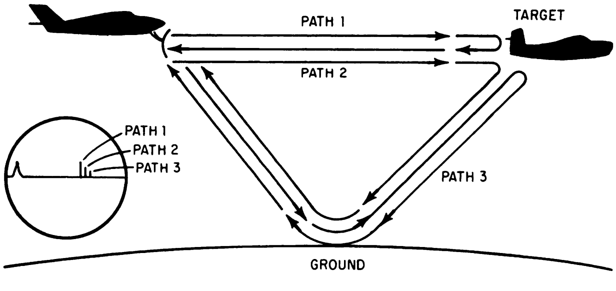
Range resolution is the minimum distance which two targets must be separated to appear as two separate displays on a scope. This separation is largely determined by the pulse width of the echo being returned to the receiver. In our typical conventional radar with a 2-μsec pulse width, range resolution would be 1,000 feet. In the pulse compression radar, the 10-μsec returned pulse is compressed to 0.1-μsec before being applied to the receiver. Therefore, the range resolution is 0.1 x 500 or 50 feet. This improved range resolution is accomplished without affecting maximum range because the envelope power is not changed.

Height Finding Capabilities

The theory employed by pulse compression to determine height is based on the ability of the radar to receive multiple path returns from a single target. With sufficient power, receiver sensitivity, and range resolution, the system can distinguish between three echo returns. (See fig. 17-32.) By measuring the time diference of the three returns and comparing the altitude of the radar transmitter, the computer can determine the target altitude. Only the pulse compression radar has both the power and range resolution necessary for this type of altitude determination.

ECM Deception

The pulse compression radar depends on the phase and frequency characteristics of the transmitted pulse to determine whether or not to accept a returned signal. If the phase and frequency do not match the transmitted pulse, compression will not take place and the signal will not pass through the receiver.



AQ. 104

Figure 7-32. –Multiple echo paths.

Signal-to-Noise Ratio

Due to the response of the matched filter to the definite phase and frequency characteristic of the transmitted signal, and the attenuation of other signals, the pulse actually applied to the receiver has a signal content much higher than its content of random noise. The signal-to-noise ratio of the system will be improved by a factor equal to the compression ratio over conventional radar.

Target Velocity

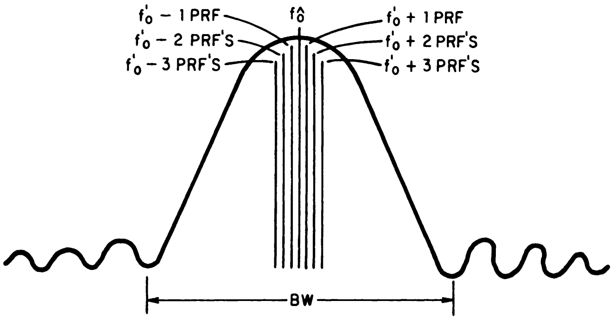
Target velocity can be rapidly determined by the use of a computer and sideband inversion. If a signal receives up Doppler, after sideband inversion the shift will appear as down Doppler. By shifting the local oscillator frequency above and below the returned echo on alternate pulses, the Doppler can be changed from up to down alternately with each transmitted pulse. This will produce a shift equal to twice the normal Doppler shift and will make it possible to determine target velocity in a time equal to two PRT. This principle could be easily incorporated. Sideband inversion is explained in detail later in this discussion.

PULSE EXPANSION

The pulse expansion operation will utilize a 0.1-μsec pulse and expand it to 1-μsec. Then stagger delay (frequency) the 1-μsec pulses to form a 10-μsec chain of pulses for transmission. The overall operation is to generate a 0.1-μsec pulse and, after expansion, transmit a 10-μsec pulse.

Spectrum Generation

RF energy is generated by a Coherent Master Oscillator (COMO) which is gated with a square wave of the desired time duration. For discussion purposes we will use a COMO with a center frequency of 100 MHz which is gated for 0.1-μsec at a PRF of 300 Hz. When this pulse is produced, it contains not only the basic frequency, but also many other frequencies within a spectrum as illustrated in figure 7-33. While



AQ. 105

Figure 7-33. —COMO output.

the difference between each frequency is determined by the PRF, the pulse width determines the bandwidth and therefore the number of frequencies within the spectrum is controlled by both PRF and pulse width.

In figure 7-33 the frequency which has the largest amplitude is the resonant frequency of the signal source by means of which this spectrum was created. Numerous other frequencies result on either side of f_o. Those above f_o will be f_o plus one PRF, f_o plus 2 PRF's, etc. At this rate, numerous different frequencies are present, each 300 Hz apart, and each smaller is amplitude as these frequencies approach the upper bandwidth limit.

Those below f_o will be f_o minus one PRF, minus 2 PRF's, etc. At this rate numerous different frequencies would be present, each one lower in frequency by 300 Hz, and each one lower in amplitude as the lower bandwidth limited is approached.

Since the COMO is gated for 0.1-μsec of time, the COMO will generate a spectrum with bandwidth of 20 megahertz. Bandwidth is determined by dividing the pulse width into 2. NOTE: In order to receive and to reproduce satisfactorily rectangular pulses equal in amplitude to the noise voltage, the receiver bandwidth in hertz should be approximately 2, divided by the pulse width in seconds. Therefore, a 0.1-μsec pulse width will generate a 20-megahertz spectrum bandwidth. Because each different frequency between the bandwidth is 300 Hz apart, over a 20-megahertz bandwidth, there are 66,666 different frequencies contained in this frequency spectrum.

Matched Filters

For this discussion our matched filter will consist of 10 channels. Each channel will have one or more amplifiers (one of which must be tuned) and a delay line as shown in figure 7-34. Each channel has individual gain and frequency controls with a bandwidth of 1 MHz. The amplifiers are tuned to successive frequencies 1 MHz apart so that their response curves overlap at their half power points as shown in figure 7-35. The entire filter band pass will be 10 MHz from the center of the above described spectrum. The filter will now respond to 33,333 difference frequencies with each channel responding to 3,333 different frequencies. The 10 sections with their respective delay lines are connected with parallel inputs and all outputs connected to a summing amplifier to produce a single output.

The entire frequency spectrum bandwidth (20MHz) is applied to the input of each of the 10 channels through the delay line (all except channel 1 which has no delay line).

Each of the 10 channels is tuned so as to cover only a small part of the total frequency spectrum. Since there are only 10 channels, each with a bandwidth of 1 megahertz, only one-half of the overall spectrum is covered. Therefore, one-half of the spectrum is not passed through the matched filter because it is not within the half power points of any of the 10 channels.

This is necessary because the amplitude of the different frequencies is too great between the maximum and minimum. If the frequencies outside of the channel spectrum half power points are rejected, the amplitude difference between f_o and f_1 or f_2 is now only 3 db. This allows the gain of the channels to be within practical limits.

As was previously determined, the numerous different frequencies within the entire spectrum bandwidth were separated from each other by 300 Hz, and since the overall bandwidth was 20 MHz, there were 66,666 different frequencies. The matched filter is tuned to react to only half of the overall bandwidth, so the filter will receive only 33,333 different frequencies. This is in turn covered in 10 different steps by the 10 filters, so each individual filter will receive only 3,333 different frequencies. For ease of explanation, only 3,300 frequencies will be used in the remainder of this chapter.

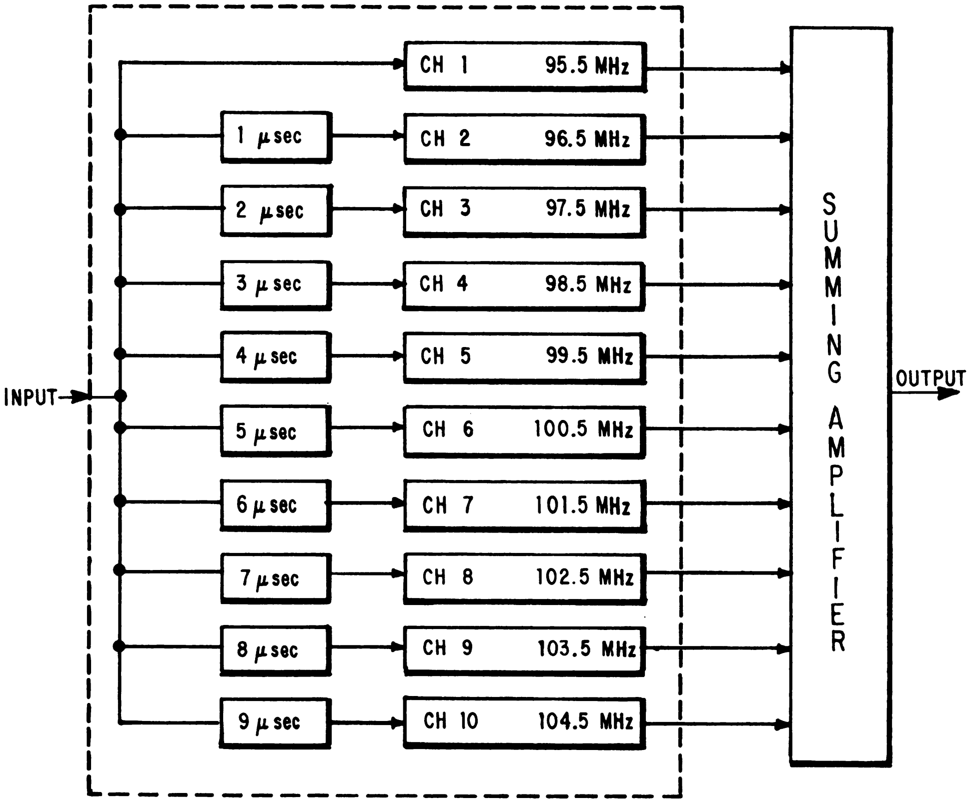


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Figure 7-34. –Matched filter assembly block diagram.

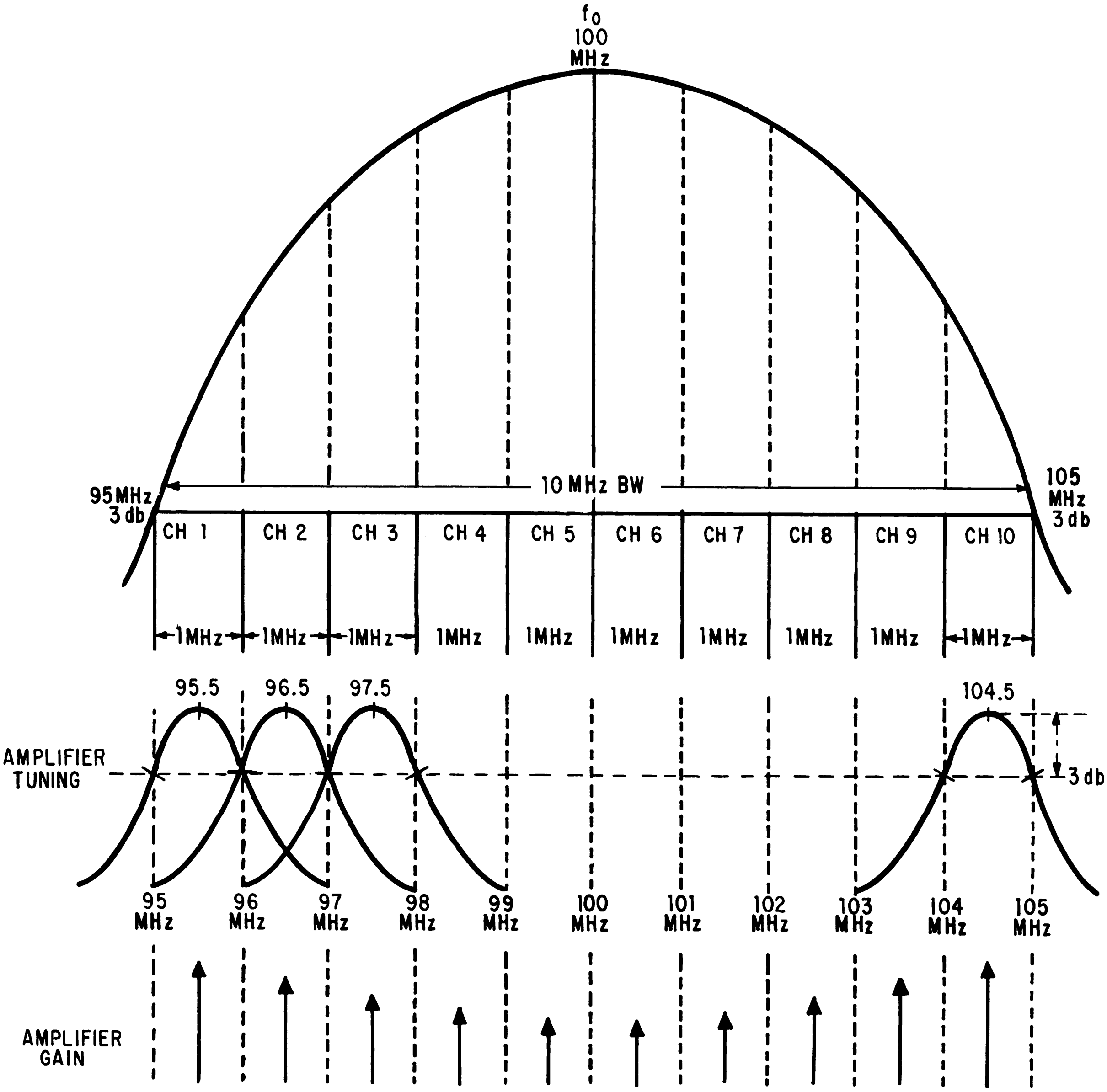
EFFECT OF A TUNED AMPLIFIER ON FREQUENCIES WITHIN ITS BANDWIDTH. –In a paralleled resonant tank circuit the voltage and current are in phase at f_o. At frequencies below f_o, the circuit appears inductive, X_L, and voltage leads the current. The farther below f_o the frequency is, the more inductive the tank appears, and the greater lead voltage has over current. At f_1, the voltage leads the current a maximum usable amount.

To frequencies above f_o, the circuit will appear capacitive by the amount that the frequencies differ from f_o. At f_2, the current leads the voltage by the maximum usable amount. Since each tank circuit in the matched filter has a bandwidth of 1 megahertz, and receives 3,300 different frequencies, approximately 1,650 of them will be above f_o, and 1,650 will be below f_o. To those above, the tank will appear capacitive. To those below, it will appear inductive. To the one frequency at f_o the tank circuit appears purely resistive.

The tuned amplifier is so designed that signal voltages are coupled out rather than signal current. To determine which signal voltages will be developed by the tank, first a reference must be used. This reference is the voltage and current which occur at f_o of the tank, and which are in phase because the tank is resistive.

The 1,650 frequencies, both above and below f_o, are applied to the tank circuit (tuned amplifier) at the same time. The voltage at the frequency f_1 of the tank will be leading the f_o current by the amount of X_L that this frequency sees.

Frequencies in between f_1 and f_o will be leading by a lesser amount because the tank circuit will appear less inductive to these frequencies. These voltages will have been advanced in phase



AQ. 107

Figure 7-35. –All channel response curves.

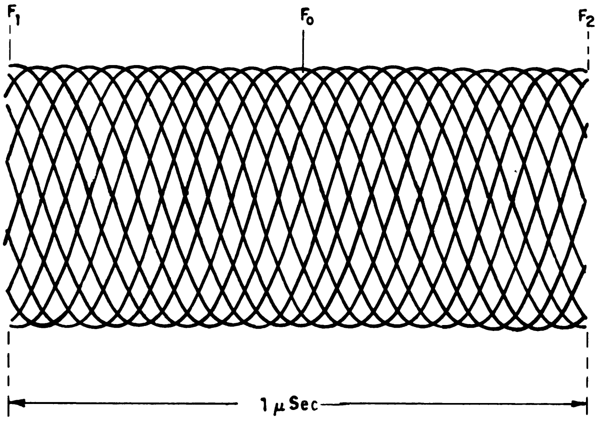
(or time) in respect to the voltage at f_0 of the tank.

The voltage of the frequency f_2 will be retarded in phase (or time) because the tank circuit will appear capacitive to that frequency. Before any voltage can be developed, current had to first begin to flow (because current leads voltage across a capacitive circuit). Voltages at frequencies in between f_2 and f_0 saw less X_C, therefore, were retarded less.

The output from this tuned amplifier will be a series of signal voltages at 3,300 different frequencies with the lowest frequency (f_1) occurring first because it was advanced the most in time, and the highest frequency (f_2) occurring last because it was retarded the most in time.

The Q of the tank circuit will be selected so as to advance the voltage at f_1 by 0.5-μsec, and to delay or retard the voltage at f_2 by 0.5-μsec.

THE TIME DIFFERENCE BETWEEN THE TIME WHEN THE FREQUENCY AT F_1 IS DEVELOPED AND THE TIME WHEN THE FREQUENCY AT F_2 IS DEVELOPED WOULD THEN BE 1-μsec. Since there are 3,300 different frequencies produced and coupled out of the tuned amplifier in a period of 1-μsec, the time delay between each of these different frequencies is 0.00031 μsec. As shown in Figure 7-36, the first frequency to leave the tuned amplifier would be the frequency at f_1 and each 0.00031 μsec thereafter, another frequency would be developed and coupled out until the frequency of f_2 is developed 1 full μsec later.



AQ. 108

Figure 7-36.–Individual channel frequency output (expansion).

Since frequency is the reciprocal of time, it can be seen that the output from each channel (1 μsec in time) will be 1 Hz wide in frequency.

What has been done is to take 3,300 different frequencies, each one in phase, and time delay or time advance each one by a different amount. This process has created a waveform which begins to appear as a linearly swept FM wave, and is called time dispersion or phase dispersion.

COMBINED OUTPUT OF THE MATCHED FILTER.–As shown in figure 7-34, the entire frequency spectrum is applied to the input of each of the 10 filter channels simultaneously, but through a delay line for channels 2 through 10. This means that channel 1 will receive its input at the instant the spectrum is applied to the input of the filter; however, channel 2 will not receive its input until later in time due to the delay line. Channel 3 will receive its input still later in time than channel 2. This process will continue so that channel 10 will receive its input last because the delay line in its input offers the largest amount of delay.

Channel 1, since it received the frequency spectrum first, will produce an output first. Channel 1 is tuned to 95.5 MHz, and has a 1 megahertz bandwidth, so it will produce in its output only that part of the spectrum from 95 MHz to 96 MHz. The frequency to first appear at the output of channel 1 will be the lowest frequency within the bandwidth of the tuned amplifier. This is because the lowest frequency receives the greatest phase or time advance because of X_L of the tank circuit at that frequency. The last frequency to leave channel one will be the highest frequency within its bandwidth. This frequency receives the most time or phase delay because of X_C of the tank circuit to that frequency. Each of the remainder of the 3,300 frequencies will be either advanced or retarded by a lesser amount, so that the time required for channel 1 to reproduce all 3,300 frequencies will be 1 μsec.

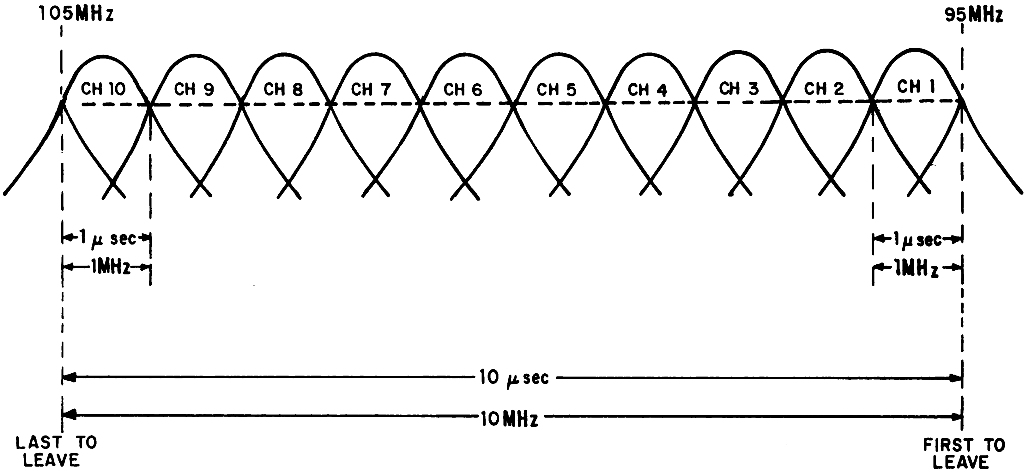
As channel 1 is finishing its output waveform, channel 2 is just receiving the spectrum at its input (because the spectrum was delayed 1 μsec by the delay line). Channel 2 is resonant to 96.5 MHz, has the same 1-MHz bandwidth, and will reproduce that part of the spectrum from 96 MHz to 97 MHz. The lowest frequency within bandwidth of channel 2 will be reproduced first because it receives the greatest advance by X_L. The highest frequency will be reproduced last because it is delayed by X_C. Channel 2 will require 1 μsec to produce its full 1-MHz output. Two μsec in time have now elapsed.

As channel 2 finishes producing its output, channel 3 receives the frequency spectrum at its input through the 2-μsec delay line. Channel 3 picks up in frequency where channel 2 left off and provides another 1-MHz part of the output for a period of 1 μsec.

This process continues until channel 10 receives the frequency spectrum at its input after being delayed by the 9-μsec delay line. It then produces the tenth part of the total output waveform which is resonant from 104 MHz to 105 MHz. It is also 1 μsec wide.

The lowest frequency of channel 1 (95 MHz) is produced, and 10 μsec later, the highest frequency of channel 10 (105 MHz) is produced. This is shown in figure 7-37.

Each of the 10 channels output waveforms



AQ. 109

Figure 7-37. –Summing amplifier output.

will be combined in the summing amplifier to produce the waveform shown in figure 7-37. This waveform sweeps a 10-MHz band of frequencies during a time of 10 μsec with a linear change of 1 MHz/1-μsec. This type of waveform is called a linear frequency modulated pulse. The matched filter which produces this type of waveform is called a LIFMOP filter being coined from LInear Frequency MOdulated Pulse. This LIFMOP waveform contains approximately 33,000 different frequencies, each one being in a very definite time and phase relationship to the others.

The output from each channel must be equal in amplitude. To insure equal amplitude from each channel, an oscilloscope is connected to observe the output of the summing amplifier. The amplitude adjustment (screwdriver adjustment) is set on each channel so that the output from each amplifier is equal in amplitude. With the oscilloscope connected to the same point, the frequency adjustment, (a technician's adjustment) is set so that the output of each amplifier coincides with the output of the amplifiers on either side of it with no interruption of the pulse. When any of the amplifiers are changed, both of these adjustments must be performed.

This LIFMOP waveform may be transmitted at these frequencies, or it may be passed through frequency converters to increase the frequency whatever is desired to be transmitted. It will normally be amplified by several RF amplifiers prior to being transmitted. These RF amplifiers, of necessity, have a very broad bandwidth and linear frequency response to avoid any type of distortion of the LIFMOP waveform. The waveform shown in figure 7-37 leaves the summing amplifier with some amplitude variations. It is desirable that the transmitted waveform have no variations of amplitude. Normally, the waveform will be passed through a limiter prior to transmit to remove these amplitude variations.

The transmitted pulse will be rectangular, swept in frequency over 10 MHz, and 10 μsec in duration. It is composed of the combined outputs of all 10 filters.

PULSE COMPRESSION

This operation is basically the inverse of pulse expansion. That is, when a 10-μsec target return is received, it is compressed so that the receiver output is a 0.1-μsec echo.

Echo Return from a Target

For discussion purposes assume that a target is located a distance from the receiving antenna so that 100 μsec of travel time will be required for the return echo to reach the receiver antenna. The lowest frequency was the first to leave the transmitter, and the first to strike the target; thus, the lowest frequency will be the first to be picked up by the receiving antenna. (It will be returned 100 μsec after it strikes the target.) The highest frequency transmitted did not leave the transmitter until 10 μsec later. It did not strike the target until 10 μsec after the lowest frequency struck the target. Therefore, it was not returned to the receiving antenna until 10 μsec after the lowest frequency was received. Refer to figure 7-38.

It can be seen that a definite time versus frequency relationship exists during the 10

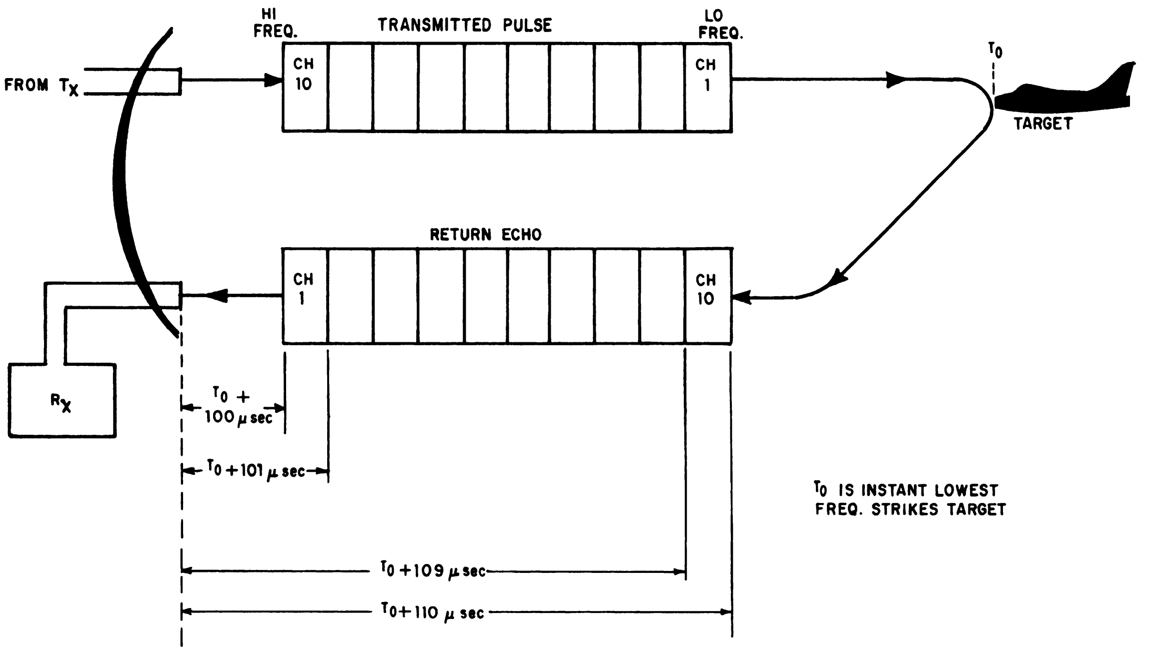


Figure 7-38. –Time function of transmitted pulse.

μsec that the returning echo is felt on the receiver input. At any time, the frequency can be determined and, therefore, which channel is receiving a signal. For instance, at T_0 plus 106 μsec, the frequency which will enter channel No. 6 is just arriving at the receiver antenna. This means that the frequencies affecting channels 1 thru 5 have already arrived, and channels 7 thru 10 are yet to come.

If the returned echo is applied to the matched filter as it is now (lowest frequency first), by action of the L and C of the tanks, the filter would tend to expand the signal again, rather than compress it as is desired. FOR THE PULSES TO BE COMPRESSED, THE FREQUENCY RELATIONSHIPS MUST BE REVERSED. That is, the returned echo must be turned around so that the highest frequency enters the matched filter first, and the lowest frequency enters last, or 10 μsec later. This is easily accomplished by sideband inversion.

SIDEBAND INVERSION. –Sideband inversion is a process of inverting the frequencies contained in the upper and lower sidebands during the process of frequency conversion. This process occurs any time the local oscillator is tuned ABOVE the frequency to be converted, and the DIFFERENCE frequency is selected. (See figure 7-39.)

NOTE: The reader should be aware that the frequency values used in figure 7-39 are arbitrary values and were selected only to illustrate sideband inversion.

From figure 7-39, it can be seen that when the upper sideband (101 MHz) passes through the mixer, the difference frequency produced is 9 MHz. When the lower sideband frequency (99 MHz) is converted, the difference will be 11 MHz. Thus, the highest incoming RF produces the lowest difference frequency, and the lowest RF produces the highest difference frequency. In the case of the pulse compression radar under discussion, the returned echo is passed through a frequency conversion stage for the purpose of sideband inverting the frequencies. The lowest frequency which was first returned will become the highest frequency after sideband inversion (95 MHz) will emerge as 105 MHz). The highest frequency (105 MHz) returning last will emerge from the mixer as 95 MHz because of this process, the entire frequency content of the returning pulse will be reversed. After this inversion, the echo is now ready to be applied to the matched filters for pulse compression.

Action of Matched Filter on the Returned Echo

The returning pulse, AFTER SIDEBAND INVERSION, is once again applied to the paralleled inputs of all 10 matched filter channels.

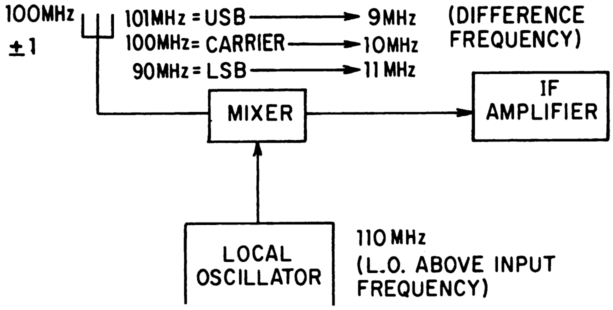


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Figure 7-39. –Sideband inversion block diagram.

The difference between the input to the matched filter, now on the pulse compression function, and the input for the pulse expansion function on transmit is that on pulse expansion, ALL frequencies (each one in phase) were present at EACH channel at the SAME TIME. But on pulse compression (or receive), the frequencies arrive ONE AT A TIME, each one separated from the others by a small phase and time difference. The first frequency to arrive, at T_0 plus 100 μsec, is the highest input frequency to the filter after conversion, and 10 μsec later, at T_0 plus 110 μsec, the lowest input frequency after conversion arrives at the filter. It must be noted that as each individual frequency arrives, it is present at the input to each one of the 10 channels simultaneously.

The highest frequency (after conversion), being the first to arrive, is applied directly to the matched input filter. Since this frequency is within the bandpass of ONLY channel 10, it will affect only channel 10. Before it can be applied to the tuned amplifier of channel 10, it receives a 9-μsec delay. Therefore, this frequency finally is present at the tuned amplifier of channel 10 at T_0 plus 109-μsec. For the next 1-μsec of time, all of the frequencies within the band pass of channel 10 will arrive and be processed. The highest frequency (105 MHz) at T_0 plus 109 μsec, is above the resonant frequency of channel 10 (104.5 MHz), so the tank circuit appears capacitive to that frequency.

The tank circuit has the same effect on frequencies ABOVE its resonant frequency that it had previuosly during pulse expansion–that is, it will delay these frequencies by an amount proportional to the amount of capacitive reactance the tank offers to that frequency. The 105-MHz signal, being the farthest away from the f_0 of the tank, will be delayed the most (approximately 0.45-μsec).

The next frequency to arrive at the tank is slightly later in time and lower in frequency, and receives slightly less delay than did 105 MHz. When 104.5 MHz arrives (at T_0 plus 109.5 μsec), the tank simply passes it exactly as it is. The rest of the frequencies within the bandpass of channel 10 are lower than the f_0 and sees an inductive reactance. This advances these lower frequencies by an amount proportional to the X_L of the tank. The 104 MHz signal, the lowest frequency within channel 10's bandpass, sees maximum inductance and is advanced approximately 0.45-μsec. The end result is that the bandwidth of frequencies of channel 10 (which was 1 μsec wide) is compressed to 0.1-μsec, and comes out of channel 10 at T_0 plus 109.45-μsec to T_0 plus 109.55-μsec. This is shown in figure 7-40.

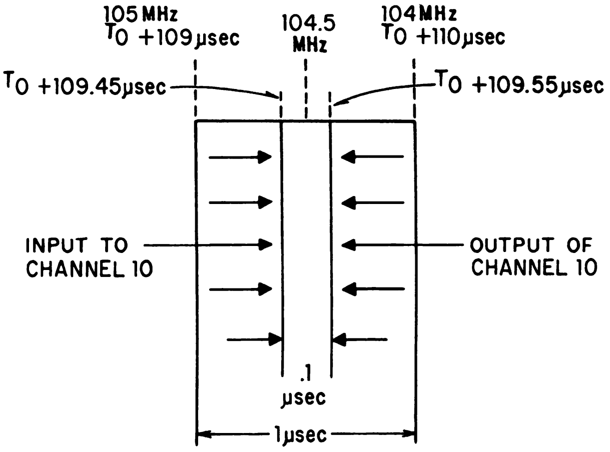

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Figure 7-40. –Individual channel compression.

The band of frequencies processed and compressed by channel 10 arrived at the receiver antenna from T_0 plus 100-μsec to T_0 plus 101-μsec. From T_0 plus 101 μsec to T_0 plus 102-μsec, the frequencies within the bandwidth of channel 9 will be arriving at the receiving antenna. To get to the tuned tank of channel 9, they must pass through the 8-μsec delay line. Then, at T_0 plus 109-μsec, the first frequency for channel 9 (104 MHz) will arrive. This frequency is higher than the resonant frequency (103.5 MHz), so it will be retarded approximately 0.45-μsec, and will be reproduced in the output of channel 9 at T_0 plus 109.45-μsec. The lowest frequency to channel 9 (103 MHz) sees maximum inductance and will be advanced approximately 0.45 μsec. Channel 9 will produce its output from T_0 plus 109.45 μ-sec to T_0 plus 109.55 μsec, or during the same time channel 10 was producing an output.

This process continues as each one of the channels receives its band of frequencies 1 μsec apart in time, but produces its output at the same time as each of the other channels. Finally, at T_0 plus 109-μsec, the first frequency to pass through channel 1 arrives at the receiving antenna, and is felt directly on the tuned tank in channel 1 since channel 1 has no delay line. Channel 1 then produces an output at the exact same time as the previous nine channels.

COMBINED OUTPUT OF THE MATCHED FILTER. -The output circuit of each individual channel is fed into summing amplifiers where all 10 outputs are combined. Because each channel produces an output at exactly the same time, and for exactly the same time duration, all 10 outputs add directly, and appear at the output of the summing amplifiers as one pulse 0.1 μsec in duration. The entire 10-μsec return echo has been compressed to 0.1-μsec, and is now ready to be detected and sent to the indication devices.

The ratio between the pulse width of the transmitted pulse and the returned compressed target echo is expressed as the compression ratio. It is determined as follows:

$$\text{Compression ratio} = \frac{\text{pulse width of expanded pulse}}{\text{pulse width of compressed pulse}}$$

The compression ratio of the radar being discussed is:

$$\text{Compression ratio} = \frac{10\text{-}\mu\text{sec}}{0.1\text{-}\mu\text{sec}} = \frac{100}{1} = 100{:}1$$

This expression is considered a figure of merit for a pulse compression type radar.

During this process of pulse compression, some apparent amplification occurs across the matched filter. This is because of the energy content and time duration of the returned echo. The 10-μsec pulse arrives with a certain volt/amps energy content, but it is compressed in time down to a pulse of 0.1-μsec. Assuming none of the energy content was lost across the matched filter, the same amount of energy must still be present in the compressed pulse. If the pulse width narrows, the amplitude of the compressed pulse will increase. This increase is the same as the compression ratio. In the radar under discussion, the pulse is compressed by a ratio of 100:1, so the amplitude of the compressed pulse is 100 times larger than the amplitude of the received target return, and still contains the same energy content.

It must be noted that in a practical radar using pulse compression, it is very difficult to get the returned energy compressed back to the same pulse width that was used in the pulse expansion sequence. As previously stated, there are many thousands of frequencies, each different by one PRF, in the transmitted pulse. Each of these frequencies bears a very definite time/phase relationship to each other. To compress the returning echo back to the original pulse width, each one of the frequencies must be present, and must still bear the exact same time/phase relationship that it did upon leaving the transmitting antenna. Due to atmospheric conditions and waveguide vibration, some atmospheric modulation occurs between pulse expansion and pulse compression. Some of the frequencies will be changed, so it will not be easy to reconstruct the original pulse. In the radar under discussion, typically the 10-μsec returned echo is compressed into a 0.2-μsec pulse, for a compression ratio of 50:1. This means that if the entire energy content is maintained across the filter, the amplitude of the compressed target video would be 50 times larger than the amplitude of the returning echo.

SIGNAL-TO-NOISE RATIO

The noise which might exist in the band of frequencies covered by the radar are at random frequencies and bearing random phase relationships to each other, and to the returning target echo. Any of these frequencies which exist within the bandpass of the matched filter passes through the filter, but are not affected by the filter. That is, they are neither expanded nor compressed because of their random relationship, so they emerge at the same amplitude at which they went in while the return echo emerges enlarged in amplitude by the amount of the compression ratio. Radars using pulse compression are generally considered to have an increase in the signal-to-noise ratio across the matched filter approximately equal to the compression ratio. This is in addition to the signal-to-noise ratio increase which might be gained by using suitable receiver input amplifiers.

ECM CONSIDERATIONS

As was previously stated, it is very difficult to jam a pulse compression type radar. This is primarily because of the characteristics of the matched filter. To overcome the target video noise jammers would have to produce enough noise signal so that the noise at the receiver antenna would be greater than the returning target echo by the amount of the compression ratio. This is easily eliminated by insertion of circuits between the antenna and matched filter which automatically reject abnormally large signals. This method is currently in use in certain long range search radars in operation with the fleet. Repeater jammers, to override the actual target return, would have to generate a spectrum containing exactly the same frequencies, each bearing the exact same phase and time relationships as that of the transmitted pulse. Even if this were possible (some types of ECM equipments simply amplify whatever their antennas receive), the ECM signal would be rejected since it would be larger in amplitude than the valid received target return. This repeater jammer could have no more delay between the time it received the transmitter's signal and the time that it retransmitted this same amplified signal than the time duration of the compressed pulse as it comes out of the matched filter. When the delay is greater than the pulse width of the compressed pulse, the indication device (computer) would see two distinct returns. One would be the target, and the other would be the ECM signal. Even if the delay was less than the pulse width of the compressed pulse, the computer would still see the target return first, then a sudden increase in amplitude as the ECM signal came through. The computer would automatically reject ECM return, but would see the target return. Chaff jamming is easily countered by the incorporation of circuits which reject abnormally slow moving targets such as chaff, corner reflectors, balloon borne devices, etc.

To further increase the difficulty in jamming the pulse compression type of radar, the PRF could be made to vary at a random rate. This will cause each and every frequency in the transmitted pulse to change slightly each time the transmitter fires. Unless the returning echo contains exactly the same frequencies that were just transmitted, the matched filter will reject them.

TRAVELING WAVE TUBES

Contrary to popular belief, the traveling wave tube (TWT) is not a new device. It was invented during the later part of World War II. Its remarkable capabilities and some of its potential applications have been known for years.

The TWT saw no practical application during the war, only an experimental laboratory device. Between 1945 and 1950, work was done to further develop the TWT for practical applications.

The Navy became interested in the traveling wave tube because of its potential applications in the communication field. However, the Navy was also considering other potential applications: radar and electronic warfare (EW) were high on the list.

The evolution of radar has partially been the result of a continuing need to stay ahead of any new countermeasure tactics which might compromise the radar's effectiveness.

The trend in search radars has been toward much higher power and toward electronic counter countermeasure (ECCM) techniques that will increase subjamming visibility. A good antijamming radar must be able to shift frequency quickly, and if possible over a wide bandwidth, to avoid the jammer's frequency. The trend in EW has also been toward wide bandwidth capability, where the jammer amplifies wide bandwidth noise or may deceptively retransmit the radar pulse to offset the radar's frequency shift tactics.

An amplifying device capable of broad operating ranges, with sufficient output power and efficiency, is necessary since wide frequency bandwidths are essential to the employment of such tactics. The TWT appeared to offer promise in these areas. The Navy, as well as other military services, has been responsible for many of the primary advances in the TWT development, principally through such organizations as the Naval Research Laboratory, the Office of Naval Research, and sponsorship of development contracts with a number of industrial firms.

The TWT is an electronic amplifying device which accepts a weak RF input signal and amplifies it many thousand times. Although it performs the same function as its principal predecessors—the triode, magnetron, and klystron, it has, however, one characteristic not shared by these devices: extremely wide bandwidth. The TWT exhibits relatively uniform characteristics within a 2:1 frequency range; i.e., within one octave. However, it can provide useful gain well outside this range. For example, TWT's are available which will amplify all frequencies from 7,000 to 14,000 MHz; others will handle frequencies from 4,000 to 8,000 MHz, etc., without having to be tuned within their bandwidths. Traveling wave tubes are not normally operated below 500 MHz nor above 10,000 MHz.

Figure 7-41 is a simplified sketch of a helix type TWT structure. At the left of the diagram is the electron gun assembly. The cathode, when heated, emits a continuous stream of electrons. These electrons are drawn through the anode; are focused into a tight, narrow beam; and are forced to travel the length of the tube, eventually to dissipate in the collector in the form of heat. At the same time the electron beam is moving through the tube, the desired RF signal is fed into a slow-wave structure consisting of, in this case, a tightly wound wire called a helix.

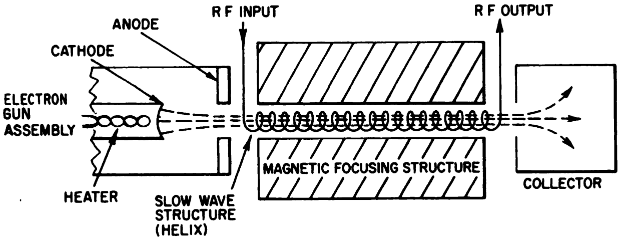

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Figure 7-41. –Simplified helix type TWT structure.

SLOW-WAVE STRUCTURE

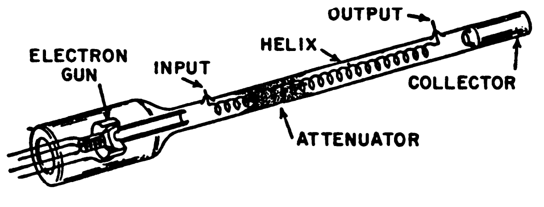
The applied RF signal propagates around the turns of the helix at approximately the velocity of light; however, the axial RF electric field (because of the signal) advances toward the collector at a velocity considerably less than the velocity of light. The rate of advance of the RF wave is approximately equal to the velocity of light multiplied by the ratio of helix pitch to helix circumference. The helix is designed to slow down the wave propagation so that it can be synchronized with an electron stream which has a velocity that corresponds to an accelerating voltage of approximately 1,500 volts.

The helix type slow-wave structure is particularly suitable for achieving wideband operation. The reason for this is that the velocity of the axial field produced by the helix is almost completely independent of frequency over a wide frequency range. A typical helix type traveling wave amplifier has a response which is constant to within ±3 db from 2,000 to 4,000 MHz.

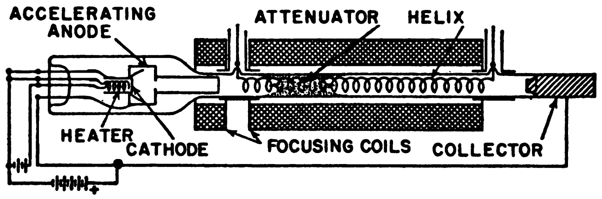
Many other types of slow-wave structures may be used in a traveling wave tube (e.g. a folded line, a periodically loaded waveguide, etc.); however, all except the helix are dispersive structures; i.e., they have a wave velocity that varies with frequency and so have less bandwidth than the helix. (Keep in mind that a traveling wave tube will amplify all frequencies for which the velocity of the wave is substantially the same as the velocity of the electron beam.) The helix type traveling wave tube is a relatively low-power device. High-power traveling wave tubes nearly always have less bandwidth.

Since the basic theory of all traveling wave amplifiers is essentially the same (regardless of the type of slow-wave structure), this discussion will be confined to the helix type.

The phase velocity of the RF wave, or the speed at which the wave is moving forward, is made synchronous with the velocity of the electron beam. The result is that an interaction is created between the electron beam and the RF signal. It is such that the electrons in the beam are slowed by the RF field and move down through the helix in bunches. As the electrons are slowed, they give energy to the RF field, resulting in great amplification of the RF signal by the time it reached the output.



(A) TRAVELING WAVE TUBE



(B) TUBE MOUNTED IN MAGNETIC FOCUSING DEVICE

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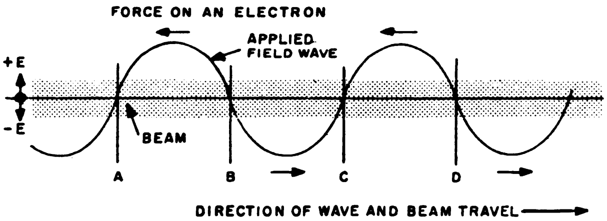
Figure 7-42. –Diagram of a typical traveling wave tube.

As shown in figure 7-42, a magnetic focusing field is provided to prevent the beam from spreading and to guide it through the center of the helix. A helix attenuator, commonly in the form of a conducting coating of aquadag painted on the glass wall of the tube, is required to prevent the amplifier from going into oscillation as the result of backward waves and/or reflections as the result of slight impedance mismatches at the terminals. The RF signal to be amplified is applied at the gun end of the helix and travels its length; output power is removed at the collector end of the helix.

INTERACTION PROCESS

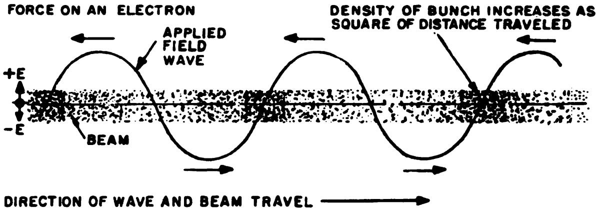
To understand the continuous interaction process, consider a constant-amplitude traveling wave of RF electric field as shown in figure 7-43. The positive half-cycle of the RF electric field is tending to force the electrons to the left; and during the negative half-cycle, the wave is tending to force electrons to the right. To begin with, a uniform distribution of electrons is traveling to the right at exactly the same velocity as the wave shown in figure 7-43.



AQ. 115

Figure 7-43. –Beginning of the continuous interaction process.

Note that electrons between C and D are falling back and accumulating at C; also, electrons between B and C are advancing and accumulating at C. In other words, a bunch is forming at C, and electrons in the half-periods on either side of B are moving away from B with the consequent formation of an antibunch at B. The bunch-formation process tends to be cumulative; that is, the longer the electrons are subjected to the field, the denser the bunch they form. The result of this process is indicated in figure 7-44. If the traveling wave field remains constant, the charge density of the bunches grows as the square of the distance traveled until the charge density approaches a maximum.

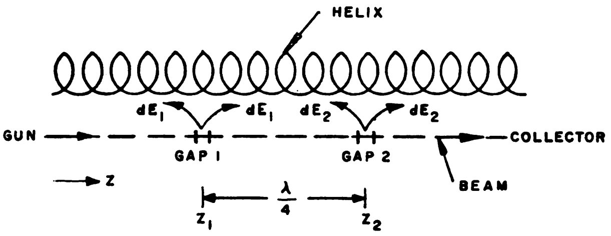

FORCE ON AN ELECTRON
APPLIED FIELD WAVE
DENSITY OF BUNCH INCREASES AS SQUARE OF DISTANCE TRAVELED
+E
-E
BEAM
DIRECTION OF WAVE AND BEAM TRAVEL

AQ. 116

Figure 7-44. –Electron bunch density grows with square of distance traveled.

It is important to note that if one observes the passage of the traveling wave and electron stream from a stationary position, the wave will appear as an a-c (RF) voltage and the bunches will appear as an alternating (RF) current. The amplitude of the alternating current (essentially charge density) is proportional to the square of the time electrons have been subjected to the field.

As these electron bunches move through the helix, they induce power on the helix and set up other traveling waves. The core of the helix may be considered to be divided into a series of gaps of infinitesimal length. The voltage across each gap and the current through each are continually changing as the traveling wave and bunches pass by them. The action of the beam may be analyzed on the basis of the action at each gap separately. Then the total effect may be obtained by adding the actions at the separate gaps in proper phase. The induced power may be resolved into an induced field wave traveling to the right, as indicated in figure 7-45. For example, at gap 1, induced field waves dE_1 are propagated to the left and right from z_1. Similar waves are initiated at all other values of z. The total field at any z is the sum of all induced waves arriving at that z from both directions.



AQ. 117

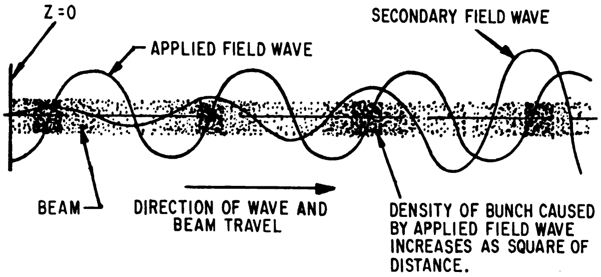
Figure 7-45. –Electron bunches induced opposite traveling field waves on the helix.

Assuming that the electron velocity is equal to the traveling wave velocity, all field waves traveling to the right will add exactly in phase and cause a secondary field wave to build up 90° behind the original applied field wave, as shown in figure 7-46. Waves traveling to the left, however, do not add in phase; in fact, some of them add 180° out of phase, and so a backward wave does not tend to build up. Note in figure 7-45 that, when a bunch passes gap 1, backward wavelet dE_1 is initiated with a positive crest; then one-quarter wavelength later, the same bunch initiates backward wavelet dE_2. By the time the positive crest of dE_2 returns to gap 1, dE_1 has passed through 180°, is at a negative crest, and the two backward wavelets will tend to cancel. Actually, dE_2 is greater than dE_1, since the bunch density is greater by the time it arrives at gap 2; therefore, a small total wave will result which is traveling to the left. It is traveling, however, at such a high velocity relative to the beam that it will cause no further interaction with the beam. It can be seen later that the helix attenuator prevents this backward wave from returning to the input terminal where it could cause trouble.

Secondary Field Wave

As mentioned earlier, the charge density of the bunches begins increasing as the square of the distance traveled. This causes a secondary field wave to be induced in phase with the alternating current (bunch), and therefore 90° out of phase with the original applied wave. However, the secondary field wave actually increases at a rate higher than does the current wave in the beam which induced it. The reason for this is that the bunches are actually inducing the infinitesimal waves which, in turn, add in phase to produce the secondary field wave. It can be proved mathematically that the secondary field wave increases as distance cubed.

The secondary field wave will, in turn, cause bunches to start forming 90° behind the original bunches in the same fashion that the applied field wave produced the original bunching. Since the secondary field wave is a growing wave, this new secondary bunching will increase as the fifth power of distance instead of as the square of the distance as caused by a constant-amplitude field. The secondary bunches then induce a new tertiary wave on the helix which grows as the sixth power of distance, etc.


Z=0
APPLIED FIELD WAVE
SECONDARY FIELD WAVE
BEAM
DIRECTION OF WAVE AND BEAM TRAVEL
DENSITY OF BUNCH CAUSED BY APPLIED FIELD WAVE INCREASES AS SQUARE OF DISTANCE.

AQ. 118

Figure 7-46. –The applied field wave induces an alternating current (bunching) on the beam which, in turn, induces a secondary field wave.

Total Growing-Wave Concept

The final form of the growing wave traveling down the helix may be realized by adding the series of growing waves (secondary, tertiary, etc.).

We may intuitively arrive at a conclusion by reasoning as follows: Near the input, the strongest field is the applied field, and so the field is relatively constant for some distance. The first increasing wave to have substantial amplitude will be the secondary wave, which is increasing as the cube of the distance. For some distance it will be the dominant wave and the total wave will grow as the cube of distance. Next, the tertiary wave becomes dominant, so the total field appears to grow as the sixth power of distance, etc. Thus, the rate of growth is rapidly increasing as distance increases, and as a result, the rate of growth is increasing as fast as the wave amplitude is growing; i. e., the growth is exponential.

It is obvious that this total field wave is traveling slower than the beam and the original wave, since it is composed of induced wave components, each of which lags the previously induced component by 90°. Thus, energy is actually being transferred from the beam to a composite wave traveling slower than the beam, which, according to mathematics, must be true. An important point can be cleared up now; that is, the velocity of the electron beam does not have to be greater than the velocity of the applied traveling wave in order for the mathematical requirements for energy transfer to be satisfied. In fact, their velocities must be exactly synchronized to result in the most efficient operation.

Energy Transfer

With this method of analysis, the question of how the beam transfers energy to the traveling wave is answered as follows: There is no net energy required to bunch the beam. On the average, as many electrons are speeded up as are slowed down, and no energy is transferred from the helix to the beam in producing bunching. There is, however, a perfectly real energy transfer from the bunched beam to the helix in inducing a growing field on the helix.

In terms of the picture of the beam passing through a series of interconnecting gaps, the beam delivers power to each gap in the same fashion that the bunched beam in a klystron delivers power to the catcher gap. Thus, at each stage of bunching, no energy is transferred; but in setting up each field wave (secondary, tertiary, etc.), the beam transmits energy to the helix.

ELECTRICAL CONSTRUCTION

Electron Gun

The electron gun used in a TWT is quite similar to that of a projector lens; its objective is to obtain as much electron current flowing in as small a region as possible without distortion or fuzzy edges. The design of the gun is extremely important, since the gun is the source of electrons for the beam. A wide variety of guns have been developed in an effort to improve the gun optics to provide better beams.

Cathodes have been made of many different types of materials. Two types have generally become standard–the oxide type, which has a nickel base with a barium/strontium coating; and the disperser cathode or the L-type, one version of which has an emitting surface consisting of porous tungsten through which barium atoms are dispensed from a chamber containing barium-strontium-oxide crystals. Two other types which are also used are the pressed cathode and the impregnated type.

Recently a number of tubes have been developed which have control grids. The use of a control grid makes it possible to turn the beam off and on rapidly with a much smaller voltage swing than is required when the cathode is modulated.

Helix Circuit

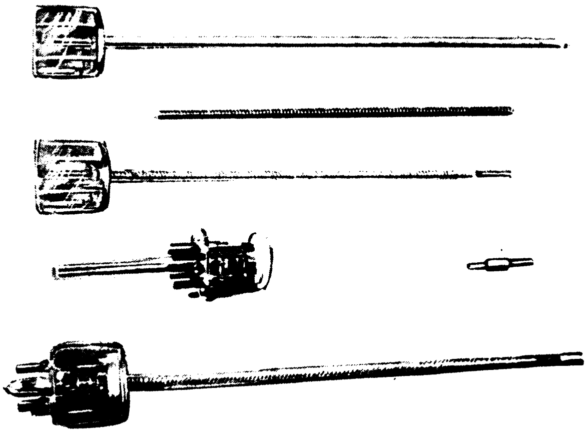
The helix circuit is considered to be the most efficient TWT circuit. It is capable of producing wider bandwidths than any of the more recently developed versions; however, its design is generally restricted to tubes having peak power outputs of less than 3,000 watts.

Single Helix

Figure 7-47 illustrates the principal component parts of a typical helix tube with its packaging and focusing structures removed. The completed tube is shown at the bottom of the figure. To the left, immediately above the completed tube, is the electron gun assembly. The helix coil, or slow-wave structure, is shown toward the top center of the figure. Helix coils are usually made of tungsten or molybdenum and are wound to extremely accurate dimensions. This accuracy is required because the fields associated with the "slow waves" must travel at the same axial speed as the stream of electrons emitted from the cathode. For example, in a 1,500-volt electron beam, the electrons travel at 1/13 the speed of light. Since the RF signal is carried along the wire from which the helix is wound at about the speed of light, the resulting linear ratio of the helix to the beam must approximate 13:1 in this example.

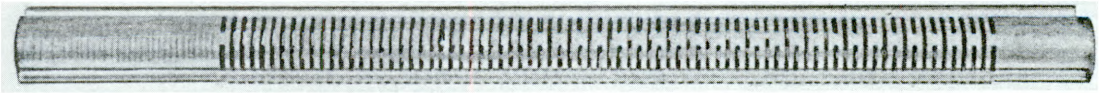
Helix-Derived Circuits

A number of configurations utilizing the basic helix structure have been explored in an



AQ. 119

Figure 7-47.–Principal parts of the helix type traveling wave tube.



AQ. 120

Figure 7-48. –A contrawound helix.

attempt to extend its many fine properties to include higher output powers. An early attempt, the contrawound helix, uses two helixes wound in opposite directions. This device extends the useful range of operating voltages to the 20 to 70-kv range and allows the use of larger transverse dimensions at a given frequency range. The ring bar shown in figure 7-48 is a version of the contrawound helix.

Filter Type Circuit

For some time, the TWT was considered usable only as a low-power device. At high powers, the basic helix structure has two major limitations: an inherent tendency to oscillate, and the inability to dissipate the large volume of heat accumulated. Many other slow-wave structures have been investigated in an attempt to find a means of eliminating these undesirable limitations while retaining the TWT's wide bandwidth characteristics. Of the many types of circuits investigated, versions of the filter type have been shown the greatest promise.

The simple waveguide is basically a high-pass filter. If a waveguide is periodically loaded, reflections will accumulate from the loading obstacles; and the high-pass filter will become a band-pass filter with characteristics which depend on the nature of the periodic loading.

Fundamental Forward-Wave Circuits

A number of circuits have been developed which employ a perturbation of the basic waveguide mode, where the fundamental wave has its phase and group velocities in the same direction. One of these, the cloverleaf, which is so named because the couplers resemble a four-leaf clover, has achieved up to 2 megawatts of peak power at S-band over a 10-percent frequency bandwidth with gains of 20 to 30 decibels.

Spatial Harmonic Circuits

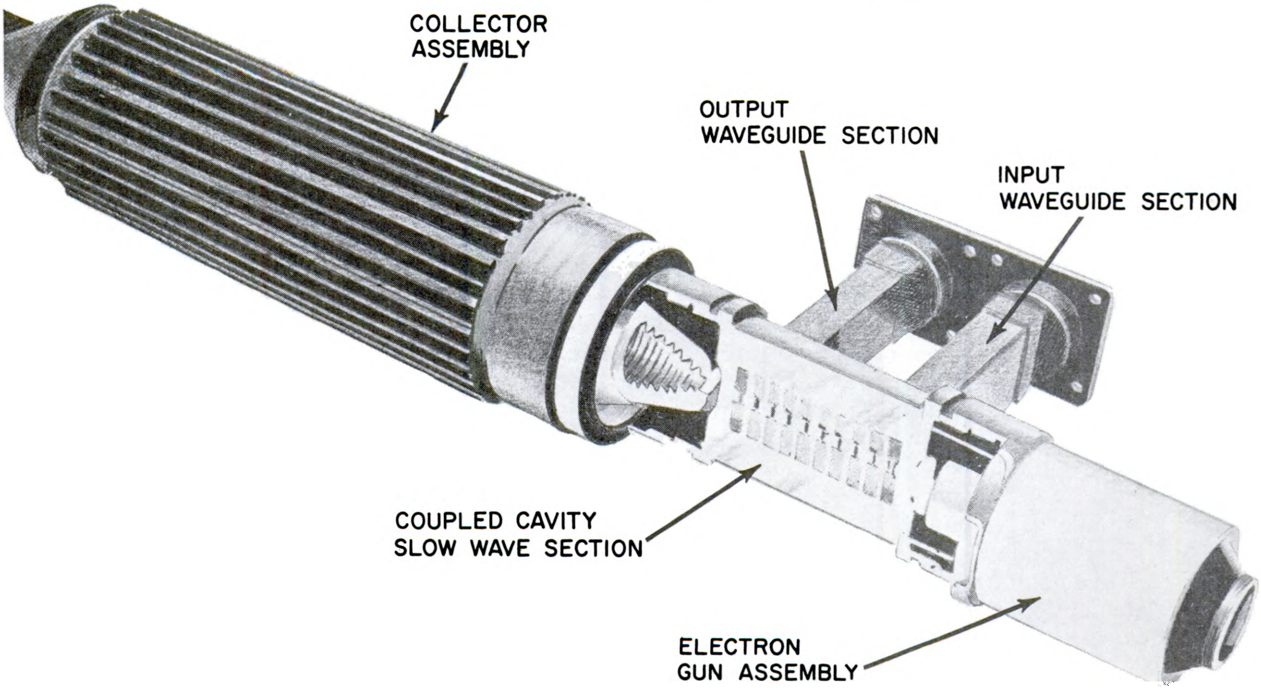
Another broad group of circuits utilizes a coaxial mode perturbed by the waveguide wall. The fundamental wave in these circuits has its phase and group velocities in opposite directions; therefore a harmonic, usually the first, is used. (These are all either backward-wave amplifiers or backward-wave oscillators. Spatial harmonics are also called Hartree harmonics and should not be confused with frequency harmonics. All spatial harmonics are of approximately the same frequency, but are developed at different times as the electron bunch travels through the slow-wave structure; i.e., they are related to the periodicity of the slow-wave structure.) The single slot, double slot, and drift tubes are examples of spatial harmonic circuits. Double slot TWT's have been built which produce 1-megawatt peak output power over a 9-percent bandwidth, with gains also in the 20-to-30 decibel region.

Coupled-Cavity Circuit

One of the most significant developments in recent years has been the utilization of basic waveguide mode resonators, coupled together by means of capacitive or inductive apertures, to provide either a fundamental forward or backward-wave circuit. This device is known as the coupled-cavity circuit. It is also known as a folded-waveguide circuit, since its structure resembles a waveguide folded in accordion fashion. Figure 7-49 illustrates a cross-section view of a high-powered, coupled-cavity tube of the spatial harmonic variety. The gun assembly is shown at the right end of the tube. The input waveguide is at the top right of the slow-wave structure; the output is to the left of the input. The cylindrical structure at the left end of the tube is the collector.

Originally, these structures provided frequency bandwidths of 10 to 15 percent. Recently, however, means have been developed for increasing the bandwidth of these circuits to 40 percent and more; and tubes utilizing this circuit have produced several hundred kilowatts of peak power at S- and X-bands, with up to 50 decibels of gain.

Another version of the coupled-cavity circuit, the interdigital line, has found extensive



AQ. 121

Figure 7-49.—High-powered coupled-cavity traveling wave tube.

use in low- and medium-power amplifiers ranging in power output up to 1-kilowatt peak, with gains of about 30 decibels.

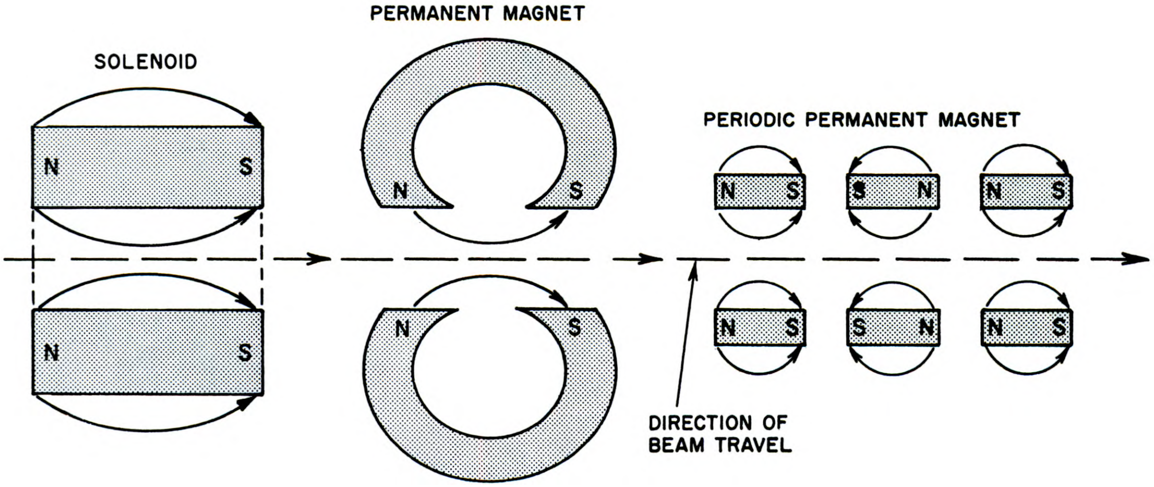
Helix Attenuator

The helix attenuator, shown in figure 7-42, was mentioned early in this chapter, but the effect that it has on the traveling waves has been ignored. It is important to note that the attenuator absorbs not only the undesired backward and reflected waves, but it also absorbs the desired forward applied field wave and growing wave on the helix. In other words, no traveling wave gets past the attenuator in either direction. However, the bunching of the electrons, which the applied wave has accomplished prior to the attenuator, is unaffected by the attenuator. As the bunches of electrons emerge from the attenuating region, they induce the secondary field wave just as described here and shown in figure 7-46. The helix attenuator does not alter the basic theory; but, if we had included the attenuator on the left side of figure 7-46, the applied field wave would not appear on the output side of the attenuator.

Focusing Structures

Since the beam tends to disperse or spread out as the result of the mutual repulsive forces between the electrons, some means is required for holding the electron beam together as it travels through the interaction structure of the tube. A magnetic field of the proper magnitude is used to confine the electron beam to the pencillike cylindrical shape it must maintain. The three principal types of magnetic focusing discussed in this chapter are illustrated in figure 7-50.

SOLENOID FOCUSING.—The solenoid is still regarded as one of the best magnetic focusing structures. Its magnetic lines are parallel to the direction of travel of the electrons; it can be accurately alined with the beam; and it provides excellent beam columniation. It will continue to be used in cases where the last bit of average power is required from a tube and tube size and weight are not critical factors. To date, most of the very high-powered TWT's utilize solenoids. Figure 7-51 shows a very high average powered TWT utilizing a coupled-cavity interaction structure with solenoid focusing.

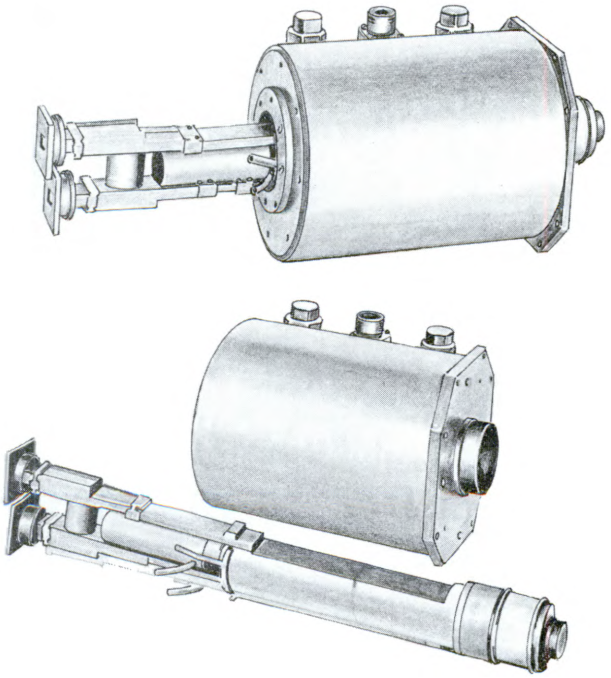


AQ. 122

Figure 7-50.—Three principal types of magnetic focusing.

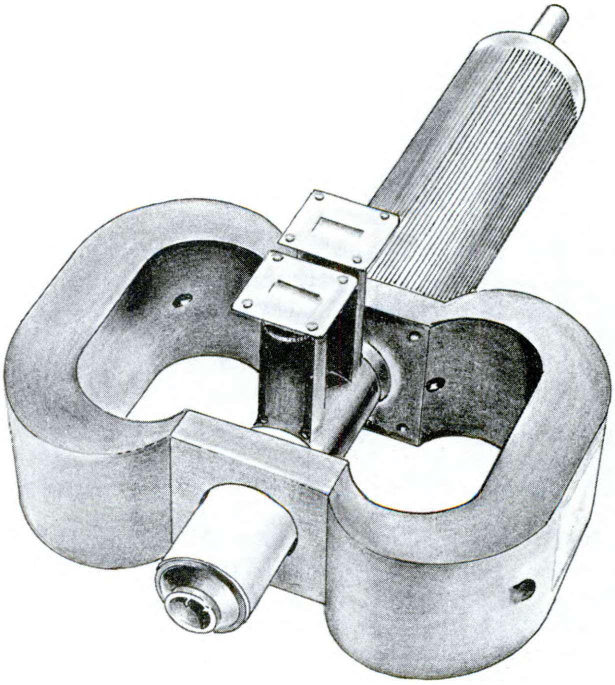
PERMANENT MAGNET FOCUSING.—In certain tube structures where the interaction structure is short enough, permanent magnet focusing is utilized in lieu of the solenoid. Figure 7-52 illustrates a coupled-cavity type TWT with its permanent magnet focusing structure.

PERIODIC PERMANENT MAGNET FOCUSING.—Perhaps the most important development in beam control has been the evolution of periodic permanent magnet (PPM) focusing, particularly its adaptation to high-powered TWT's. Previously, its fundamental limitations were



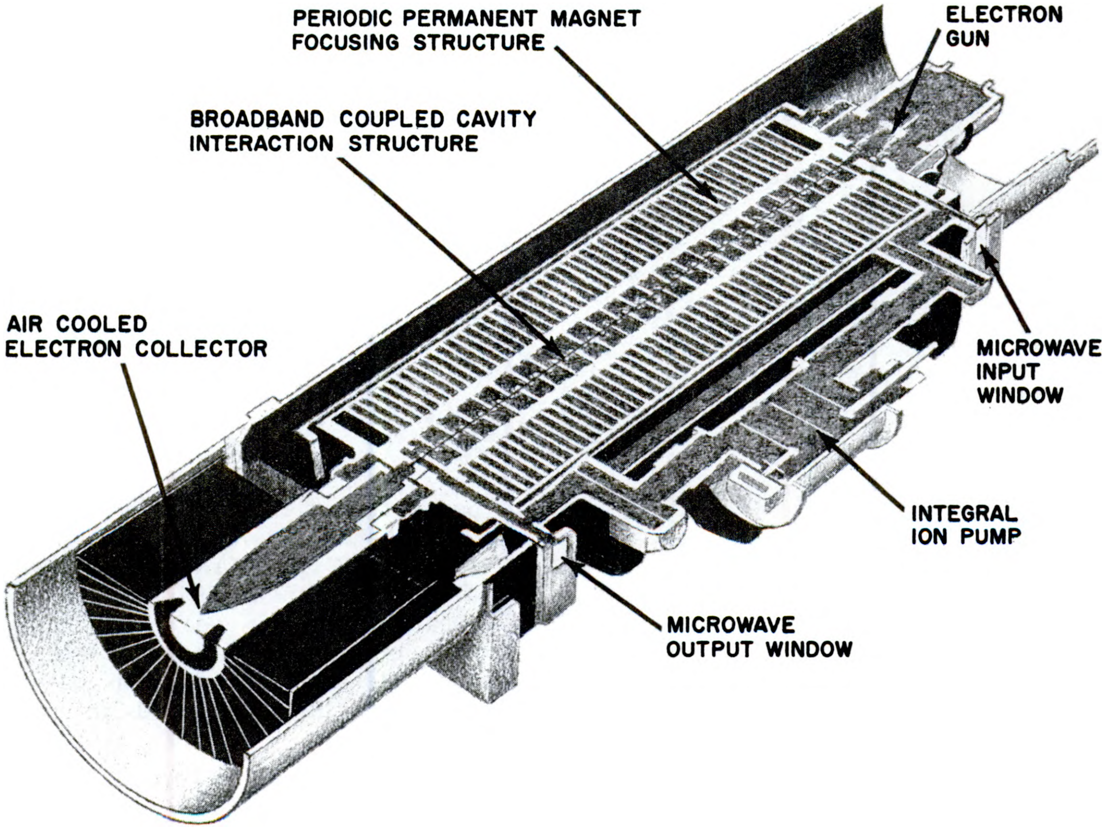
AQ. 123

Figure 7-51.—High-powered TWT using solenoid focusing.



AQ. 124

Figure 7-52.—High-powered TWT using permanent magnet.


PERIODIC PERMANENT MAGNET FOCUSING STRUCTURE
ELECTRON GUN
BROADBAND COUPLED CAVITY INTERACTION STRUCTURE
AIR COOLED ELECTRON COLLECTOR
MICROWAVE INPUT WINDOW
INTEGRAL ION PUMP
MICROWAVE OUTPUT WINDOW

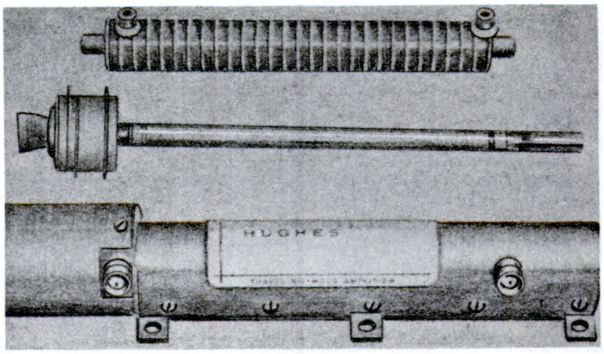
AQ. 125

Figure 7-53. –High-powered TWT using periodic permanent magnet (PPM) focusing.

thought to restrict its use to low-powered TWT's, where the beam power density is typically quite low. This lightweight focusing method fills a great need at the high-power levels where previous TWT's (with focusing solenoids) were too large and heavy for many airborne and space applications.

Figure 7-53 shows a cross-sectional view of a high-powered X-band TWT, complete with focusing structure and external package. The tube is the metal-ceramic, coupled-cavity type and has a total weight of 15 pounds. Its magnetic structure is composed of round disks represented in the cross section by the black vertical areas at the extremities of the interaction structure. These magnets are separated by the lighter colored, iron pole pieces which function as magnet separators and form the interaction structure of the tube.

Figure 7-54 illustrates the use of PPM focusing in a helix type, metal-ceramic TWT designed for space application. The PPM



AQ. 126

Figure 7-54. –Helix type TWT using periodic permanent magnet (PPM) focusing.

assembly is shown at the top of the figure. This structure is slid onto the helix tube (shown in the middle of the figure), properly alined, and finally packaged as indicated at the bottom of the figure. The tube provides 10 watts of CW power at S-band and has a total packaged weight of only 12 ounces.

ELECTROSTATIC FOCUSING.–Electrostatic focusing methods have been experimentally applied to low- and medium-powered TWT's with some success. Electrostatic focusing techniques require no magnetic field and, in principle, could provide even greater compactness and lighter weight than the PPM. However, the techniques currently available have not reached the practical stages where they can successfully compete with PPM focusing.

Collector

The only function of the collector is to dissipate the electrons in the form of heat as they emerge from the slow-wave structure. This is usually accomplished by conduction to a colder outside surface, where the heat is absorbed by circulated air or liquid. The collector size is determined by the method of cooling used and the amount of energy which must be released.

MECHANICAL CONSTRUCTION

A conceivable disadvantage of the helix circuit has been the fragile glass vacuum envelope which encloses the tube parts. Actually, however, such glass structures are sufficiently well supported to withstand almost any environment and can tolerate very high shock and loads.

Recently, a means of utilizing metal and ceramic materials in place of glass in helix tube manufacture has been developed. These tubes can withstand higher loads and can be vacuum-fired at higher temperatures–typically 600°-700° C as opposed to 450° C. This assures considerably better cleanup of undesired gases entrapped in the tube, providing improved reliability at higher tube operating temperatures. Figure 7-54 illustrates a very recent version of such a tube. Most other structures discussed in this chapter utilize metal-ceramic construction.

FUTURE DEVELOPMENT AND TRENDS

A capability to amplify over a very wide bandwidth has great significance today in military applications. As a result of the wider bandwidth and higher power capabilities of some of the newer tube types, principally the TWT and its relative, the carcinotron, many existent radar and ECM system designs will rapidly become obsolete.

The efforts of some tube manufacturers to develop higher average powers are being concentrated on CW rather than on pulsed TWT's. Recent requirements for sophisticated Doppler radars, high-power ECM, and space communications have demonstrated an urgent need for high-powered devices, but only over limited bandwidths. It is expected that TWT's will soon be developed which will be capable of replacing these devices, thereby providing vastly superior system capability.

Space applications of radar and electronic countermeasures can be expected to expand along the lines of recent communications developments. Just which radar and ECM techniques will be used in space will depend on the design and mission of the coming space vehicles. Satellites performing reconnaissance and surveillance missions will probably be among the first developed, and it is likely that TWT's will be at the forefront of their systems.

The electronic efficiency of TWT's in other areas is continuously being studied and improved; and efficiency as great as that provided by any other type of structure is being attained. TWT's are beginning to invade both ends of the microwave spectrum. At the lower end, they are replacing triodes in a number of applications; and at the high end, millimeter wave TWT's are showing excellent progress. At high frequencies this device will offer tremendous communications versatility because it combines broadband frequency range with the security provided by line of sight transmission and reception.

CHAPTER 8

ANTENNAS

As an Aviation Fire Control Technician First Class or Chief, you will be required to supervise and instruct others in the maintenance of antennas and antenna systems. Therefore, it is essential that you have a knowledge of antenna principles and their application in aviation fire control equipment.

The fundamental principles of operation for antennas in UHF and microwave ranges are the same as those used at the lower frequencies. These principles are covered in chapter 13 of Basic Electronics, NavPers 10087-B, and are not discussed in this chapter. Therefore, it is recommended that the material in the basic text be reviewed before continuing in this manual. The material presented in this chapter is relative to antennas and antenna systems employed by aviation fire control equipment.

ANTENNA CHARACTERISTICS

After an RF signal has been generated in the transmitter, there must be a means of radiating this signal into space, and a means by which it may be intercepted (picked up) for use by the receiver. The device which fulfills both of these requirements is the ANTENNA. The major purpose of a transmitting antenna is to convert the transmitter's RF energy into electromagnetic fields suitable for propagation into space as efficiently as possible. The major purpose of the receiving antenna is to intercept the reflected electromagnetic fields from the target(s) and to change these fields into an RF signal which the receiver is capable of accepting and amplifying.

The process by which the RF energy is converted into electromagnetic waves and radiated into space is called PROPAGATION. Certain basic concepts of antenna propagation are included in chapter 13 of Basic Electronics. These basic concepts should be thoroughly understood.

In the study of this chapter, it should be kept in mind that the subject matter field is broad and no attempt at complete coverage is made. Rather, only such background information that will be of help to the AQ is included. In many instances, the AQ will have the assistance of field engineers, or he will at least have specific instructions on how to perform many jobs. Therefore, he will, in practice, need much of the information contained in this chapter only as a necessary background.

DIRECTIONAL PROPERTIES

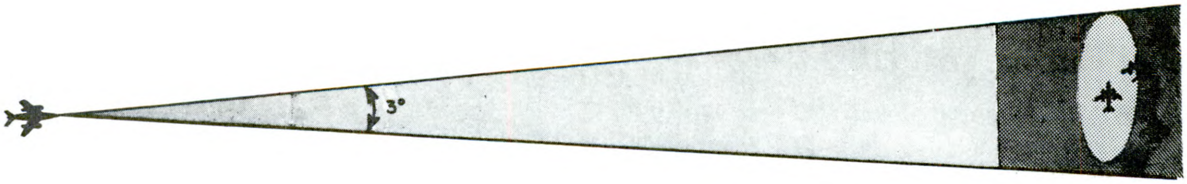
One of the most important characteristics of a radar antenna is its directivity. An antenna may radiate energy equally well in all directions or it may radiate in one specific direction better than other directions. However, all antennas are directional to a certain extent—some only slightly and others considerably more.

In aviation fire control radar, the directivity of an antenna is an important factor. An antenna that is highly directional will radiate a maximum amount of energy in a specific direction. Thus, maximum illumination of the target is accomplished. Maximum illumination of the target or concentration of the radiated energy will result in greater range capabilities of the radar set, better target definition, and greater accuracy in determining the position of the target. Since an antenna receives from the same direction that it radiates, the position of the antenna at the time of target reception is indicative of the relative target position.

There are several methods of controlling the directivity of an antenna in its design. Most antennas found in aviation fire control radar employ a parabolic dish type device as a reflector for the radiated energy. It serves to reflect the radiated energy in much the same manner that light rays are reflected.

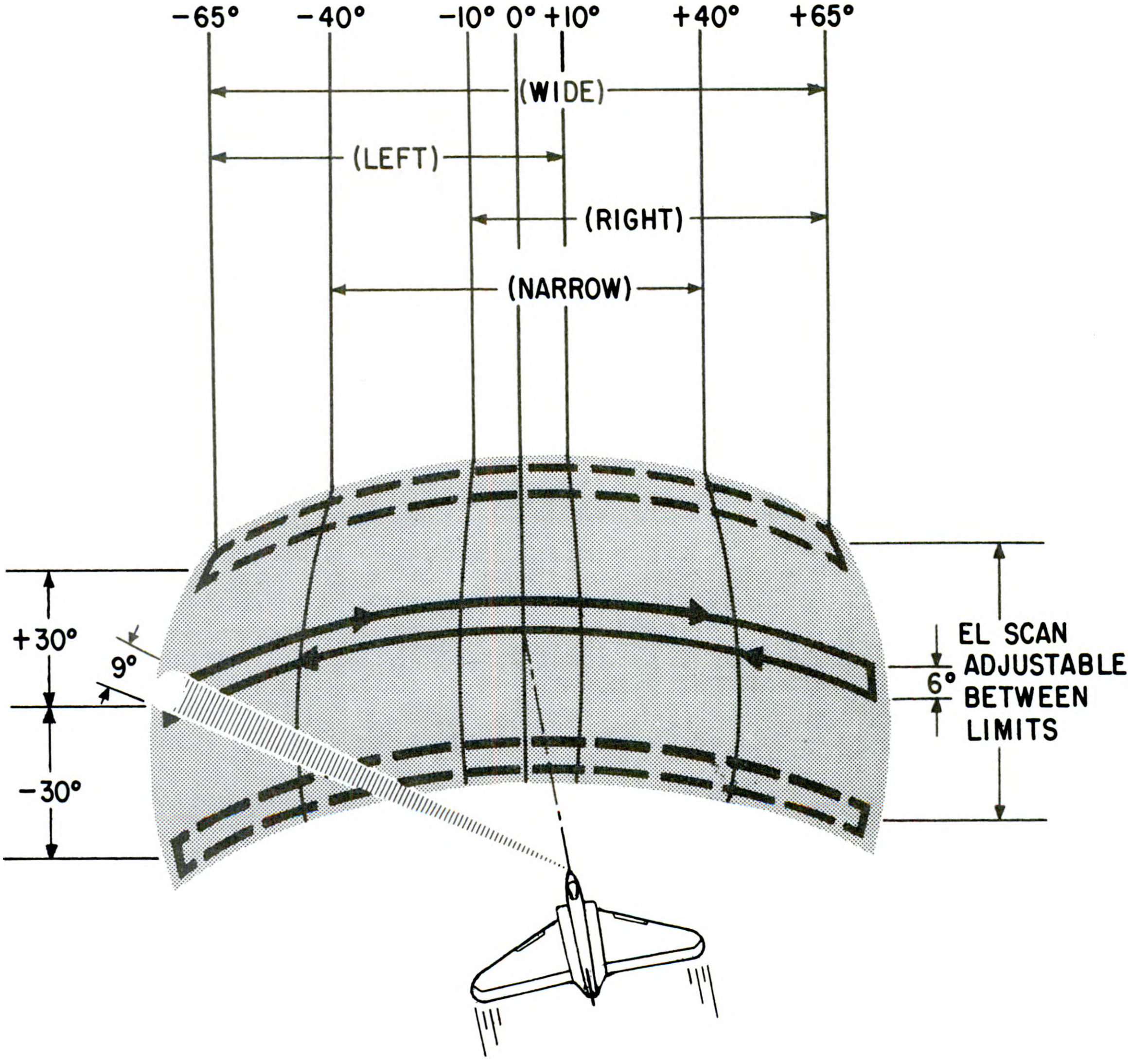
The degree of directivity of an antenna is referred to as its beam width. If an antenna is capable of radiating a cone of energy with a 3° apex, the antenna has a 3° beam width in both the vertical and horizontal planes.

The use of a narrow beam width will result in more accurate target position determination. Most fire control radar antennas radiate energy into space in narrow pencil type beams or lobes, especially those used in the detection of airborne targets. Figure 8-1 is an illustration of such a radar beam.



AQ. 127

Figure 8-1. –Pencil type radiation pattern.



AQ. 128

Figure 8-2. –Conical beam sector scan.

It may be noted that the larger the reflector, in terms of wavelength, the narrower is the beam width. The actual physical size, however, is limited by the space available in the aircraft. Therefore, the tendency toward higher frequencies enables us to use a smaller "dish," allowing greater flexibility in locating the antenna in the aircraft; or a larger dish (in terms of wavelength) may be used with an improvement in beam width.

In radar bombing equipment, it is desirable to cover a larger surface area ahead of the bombing aircraft. Thus, a beam that is narrow in the horizontal plane and wide in the vertical plane is desirable and results in a narrow blade type beam. Accurate directional characteristics in the azimuth plane will still be maintained with this type beam.

SCAN PATTERNS

Figure 8-2 is an illustration of a typical box type intercept scan pattern. The antenna radiates a conical type beam of approximately 9° which, when added to the 6° vertical "nod," gives the antenna an automatic 15° elevation coverage as it scans back and forth in azimuth. By use of an operator's control, the antenna may be made to scan at any elevation angle within the limits of the equipment.

The degree of azimuth scan may also be selected as desired by the operator in some equipments. As shown in figure 8-2, the operator may select one of the following azimuth scan patterns:

1. Wide–approximately 130°
2. Narrow–approximately 80°
3. Left–approximately 75°
4. Right–approximately 75°

In many aviation fire control radar sets, the conical type radar beam is caused to rotate (or nutate) as it scans a selected area. Figure 8-3 illustrates a nutated radar beam and the resultant coverage. The radar beam is caused to rotate in a circular motion at a specific rate by a spin motor. The spin motor mechanically drives the antenna radiator or antenna feedhorn in a circular motion and thus enlarges the illuminated area. (It should be remembered that the values shown in figure 8-3 are typical and may vary with different equipments.)

NOTE: Development of an error signal for antenna tracking was discussed in chapter 7 of Aviation Fire Control Technician 3 & 2, NavPers 10387.

Typical scan patterns found in aviation fire control equipment are shown in figure 8-4 (A) and (B). Note that the antenna is also scanned vertically in figure 8-4 (B).

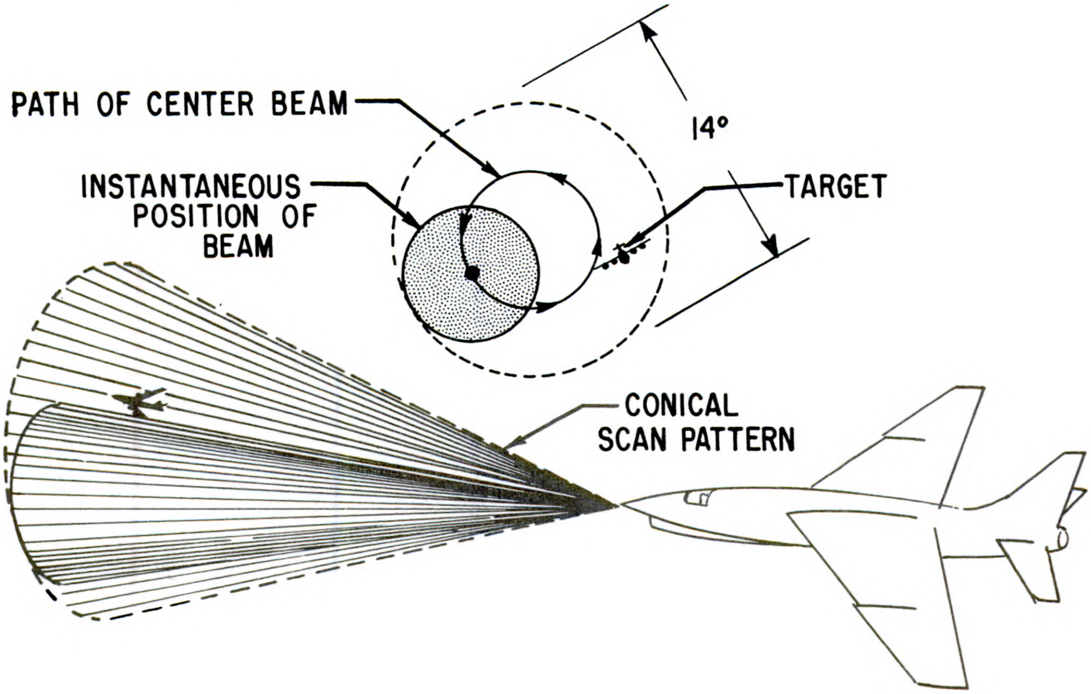
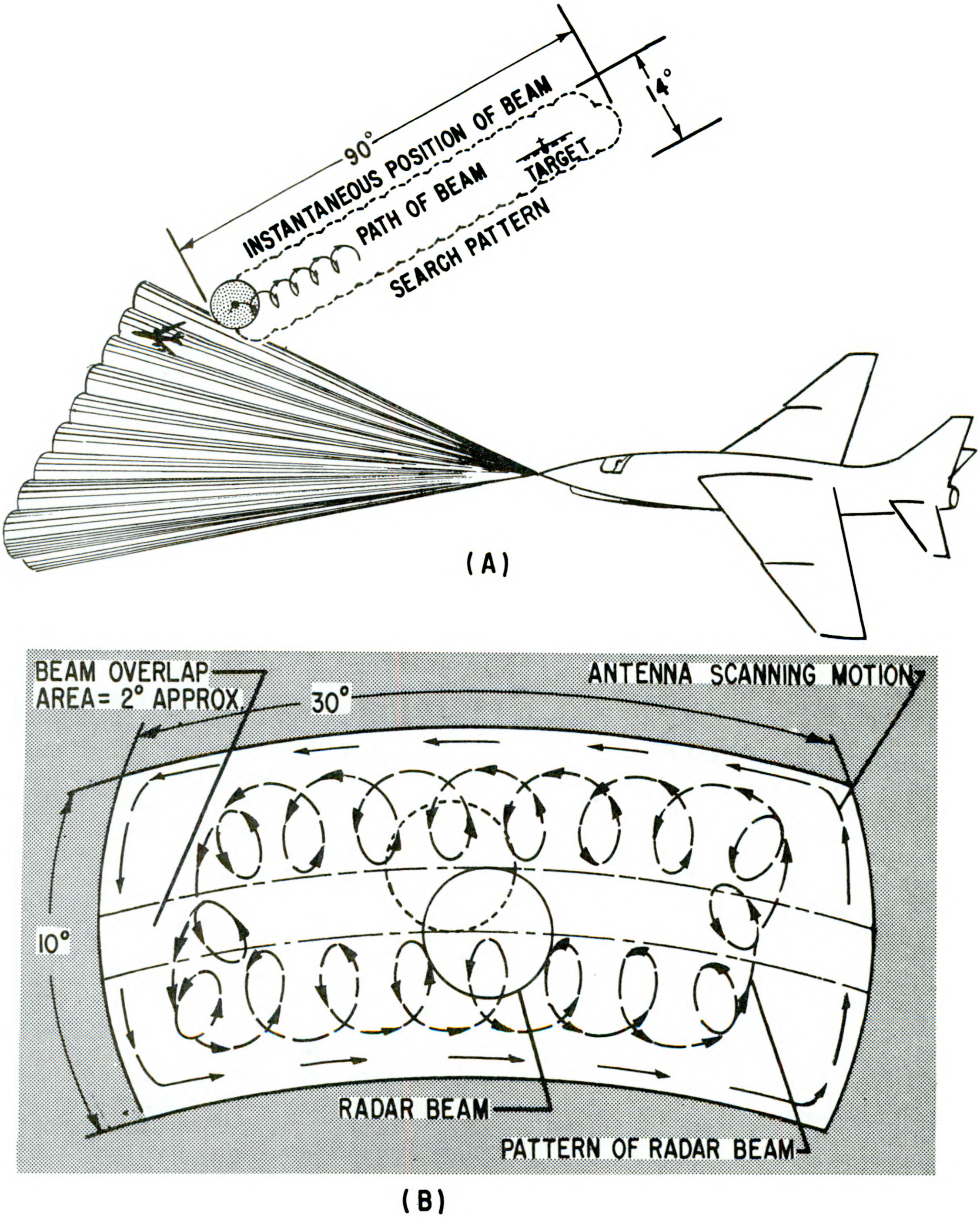


Figure 8-3. –Rotating beam pattern.

AQ. 129



AQ. 130

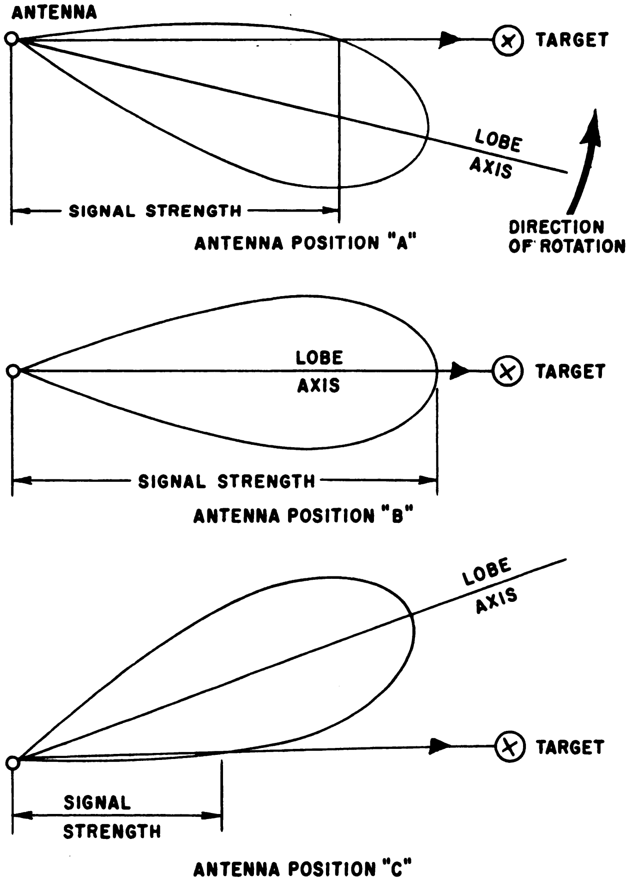
Figure 8-4. –Antenna coverage patterns.

This type scan is almost always controllable to the extent that any sector within limits of the equipment may be scanned as desired.

ANGULAR DETERMINATION

The measurement of the direction of a target from the radar system is usually given as an angular position. The angle may be measured from true north if the installation is stationary, or with respect to the heading of the aircraft containing the radar set. The angle at which the echo signal returns is measured by utilizing the directional characteristics of the radar antenna system.

The simplest form of antenna for measuring azimuth or bearing is one which produces a single lobe pattern. The system is mounted so that it can be rotated. Energy is directed across the region to be searched, and the beam is scanned in azimuth until a return signal is picked up. The position of the antenna is then adjusted to give maximum return signal.

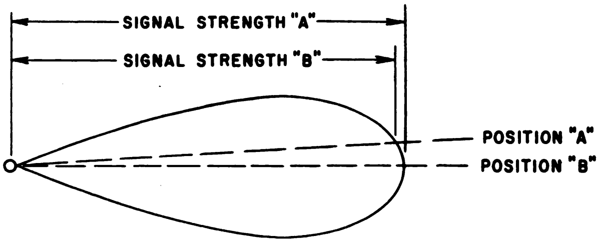


AQ. 131

Figure 8-5. –Relationship between beam axis and target bearing.

Figure 8-5 shows the receiving pattern for a typical radar antenna. Relative signal strength is plotted against angular position of the antenna with respect to the target. Maximum signal is received only when the axis of the lobe passes through the target.

The sensitivity of the single lobe system depends on the angular width of the lobe pattern. The operator adjusts the position of the antenna system for maximum received signal. If the signal strength changes rapidly with angular rotation, the accuracy with which the on-target position can be selected is great. Thus, in figure 8-6 the relative signal strengths A and B have very little difference. If the energy is concentrated into a narrower beam, the difference is greater and the accuracy better.

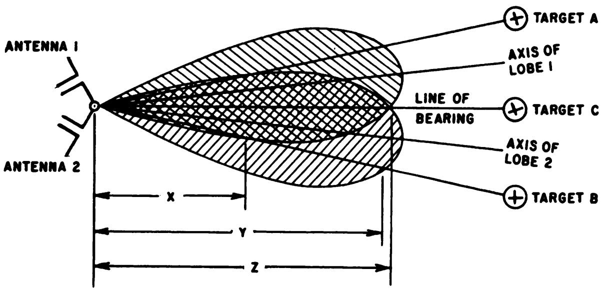


AQ. 132

Figure 8-6. –Accuracy of single lobe.

In the single lobe antenna system, the signal strength varies more rapidly on the side of the lobe than near the axis. The greatest rate of change of signal strength per degree of rotation occurs between the angles which give 50 and 85 percent of maximum. Radar systems designed for gun laying for fire control require the highest possible accuracy in measuring azimuth angles. The multiple lobe system achieves this accuracy by using two or more lobes to form the antenna system pattern.

The principle of the double lobe system is illustrated by using two separate antennas whose lobe axis are displaced by some angular distance (fig. 8-7). The two lobe patterns intersect at one point only, known as the crossover point, at which equal signals are produced by the two antennas for this particular azimuth. At all other positions of the array, unequal signals are produced. When the target is in position A, the echo signal strength received by lobe 1 is proportional to Y, and that received by lobe 2 is proportional to X. If the antenna is rotated so that the target is in position B, the signal from lobe 1 decreases to an amplitude proportional to X, while that from lobe 2 rises to a value proportional to Y. At position C, between these two positions of the antenna, the signals from the two lobes are equal and proportional to Z and the antenna system is on the bearing of the target.



AQ. 133

Figure 8-7. –Double lobe pattern.

The use of two lobes instead of a single lobe greatly increases the accuracy of azimuth measurement. The amount of increase depends on the configuration of the antenna array. In addition to the greater accuracy of the double lobe, there is another advantage in the sense of direction available. If the antenna array is off target on the side of lobe 1 (fig. 8-7, position A), the signal received by lobe 1 is the larger. Therefore, the antenna should be rotated toward the left until the signals become equal. When the amplitude of each signal is proportional to Z, the antenna is said to be on target.

Although the 2-lobe system is not used in aviation fire control, its principles may be applied to the common 4-lobe system or to the nutated beam to determine azimuth and elevation angular information.

It may be noted that there is some loss in maximum range when the target is centered between the beams. This occurs only during track modes, and maximum range in search mode is unaffected. Since ranges involved in track modes are usually less than in search, some loss in maximum can be tolerated.

TYPES OF ANTENNAS

There are many different types of antennas and antenna systems employed in the field of airborne radar. However, in this manual only those peculiar to airborne fire control radar are given consideration. There are essentially two basic types of antennas employed or used in the specialized field of aviation fire control. One type is composed basically of one element, a radiating device; the other is composed primarily of two elements, a radiating element and a reflector.

Essentially an open ended waveguide can be used to produce directional radiation. Two problems which occur are (1) how to effectively match the waveguide to free space; and (2) how to achieve a narrow beam of radiation. The radiation pattern of an open ended waveguide is broad in both the vertical and horizontal planes. It is also an inefficient system because of the mismatch between the waveguide and free space.

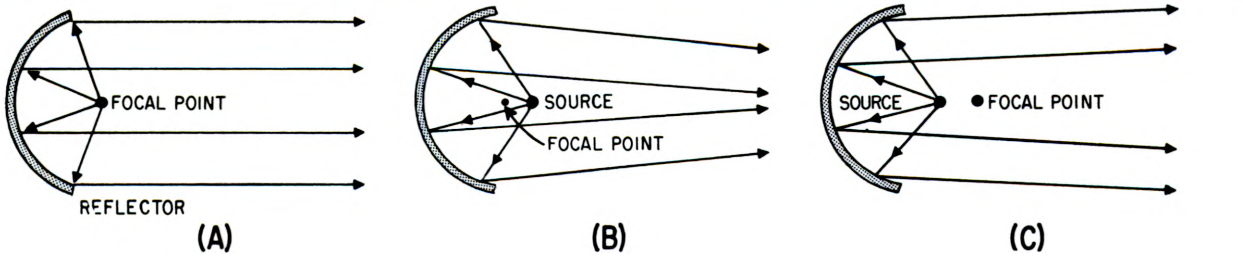
HORN TYPE

If the waveguide is flared out at a gradual angle, a horn antenna is obtained. Flaring results in a gradual decrease in guide wavelength at the mouth of the horn. The wavelength at the mouth of the horn is then nearly the same as the wavelength in space and impedance matches the wave impedance in space. The flare must be gradual or reflections will develop with resultant standing waves. At the same time a sharper beam is obtained. Horn antennas are used in aviation fire control only when a highly directive beam is not required (range only radar). In order to produce a highly directive beam, the antenna would have to be longer than practical. However, this disadvantage may be overcome by placing a lens over the mouth of the horn. Also, it might be well to keep in mind that the larger the aperture of a waveguide, the greater the gain and directivity.

PARABOLIC REFLECTOR

It was stated previously in this chapter that RF energy can be reflected in much the same manner as light rays. The parabolic antenna employs this principle and derives the name from the shape of the reflecting device called the reflector (sometimes called the dish). This type of antenna is employed extensively in aviation fire control radar equipment, especially in the equipment used against airborne targets.

This antenna consists basically of two parts–a reflector and a radiation device. The radiation device is most often a horn type element. The reflector is a metallic dish having a parabolic shape. The radiating device (feedhorn) directs the RF energy into the reflector and is essentially the open end of the waveguide which conducts the energy from the transmitter. Feedhorns may be found in various shapes, depending on the mechanical and electrical requirements



AQ. 134

Figure 8-8. –Parabolic reflector.

of the particular antenna system. Some systems may rotate or nutate the complete feedhorn, while others may rotate only a feedhorn offset.

As transmitting frequencies approach the microwave region, the similarity between light waves and radio waves becomes pronounced. Therefore, the behavior of microwave energy may be explained by the use of light waves.

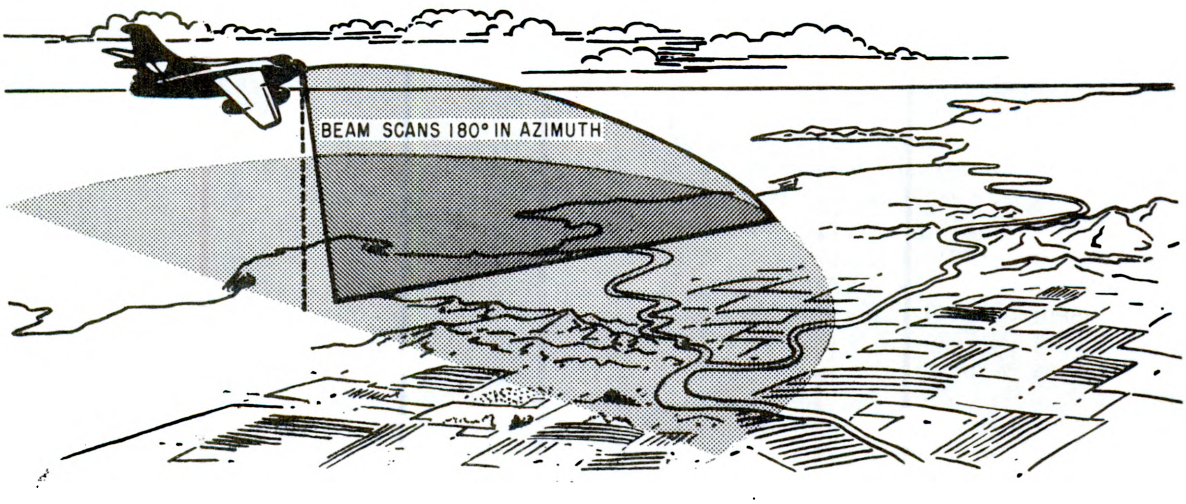
An electric bulb suspended in the exact center of a room casts its light evenly in all directions about the room. If it is desired to increase the intensity of light in one area, place a reflector behind the bulb. The reflector concentrates the light into a small beam. The amount the beam can be concentrated depends upon the shape of the reflector and where it is placed in relation to the light source. In order to obtain the best concentration of the beam, the reflector is designed to have the shape illustrated in figure 8-8 (A). This is called a parabolic reflector.

To give the best concentration of light, the light source must be located at the focal point of the reflector. (The focal point is determined mathematically for the dimensions of the reflector.) If the source of light is placed at this point, the rays will be reflected to form a narrow parallel beam of light. Should the source of light be placed a short distance outside the focal point, as in figure 8-8 (B), the rays would come together at a point some place in front of the reflector. If the source is placed closer to the reflector, as in figure 8-8 (C), the beam spreads.

As discussed previously in this chapter, the antenna beam should be conical with a beam width 3° to 9°. Therefore, the feedhorn is located slightly inward from the focal point as shown in (C) of figure 8-8.

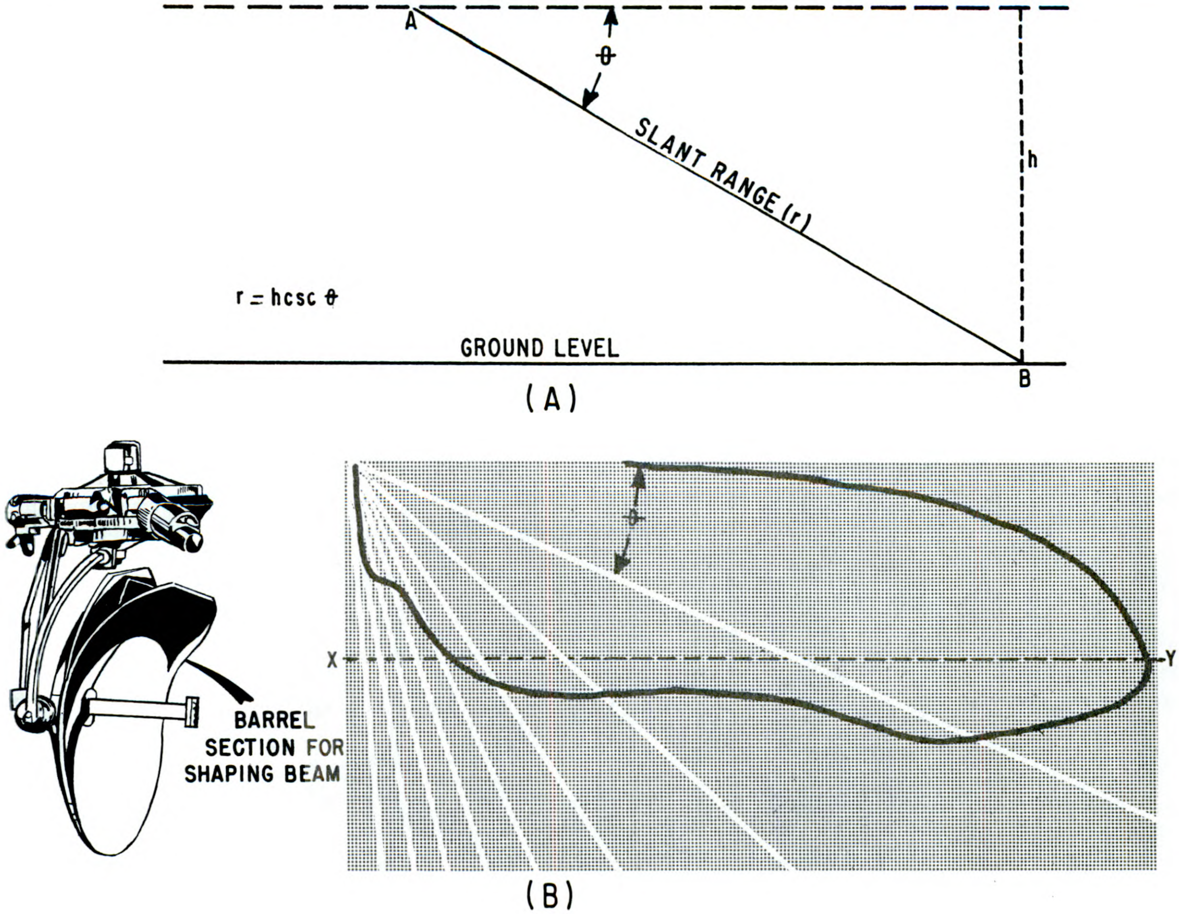
COSECANT-SQUARED REFLECTORS

The cosecant-squared reflector is a modified version of the parabolic reflector. Because of the variety of the applications of radar, widely different requirements must be met by different antennas. Antennas designed to produce special



AQ. 135

Figure 8-9. –Cosecant-squared beam.



(A)

(B)

Figure 8-10. –Cosecant-squared antenna and pattern. AQ. 136

polarization effects or pattern shapes may differ greatly from those previously described. Airborne radar sets that are designed to scan a large area require a special beam shape.

This beam should be narrow in the horizontal plane, but broad in the vertical plane (fig. 8-9). In addition, the particular area to be scanned must not be illuminated uniformly by the radar beam. Instead, the objects near the aircraft should be illuminated with less power than those farther away in the same sector, because echo signals from nearby objects will be strong due to their closeness to the aircraft. On the other hand, a greater amount of power should fall on more distant objects in this sector since they would normally produce the weakest echoes. Thus, the radiated fields of the beam should increase in strength at the greater distances. This type of pattern is employed in radar bombing equipment. Figure 8-10 (A) shows some trigonometrical relationships of this situation.

If the aircraft is at point A in figure 8-10 (A) and the target is at point B, the slant range r (straight-line distance from A to B) can be represented in terms of the aircraft altitude h and the angle of depression (θ) of the target as seen from the aircraft. This represented by:

$$\frac{h}{r} = \sin\theta \; ; \; r = \frac{h}{\sin\theta} \; ; \; r = h \csc\theta$$

Thus the slant range is proportional to the cosecant of θ.

An antenna has been designed so that the field intensity pattern is also proportional to cosecant θ. This antenna radiates a uniform electric field which causes the echo response of a nearby target to be approximately equal to that of a distant target having the same radar cross section (reflectivity). The equality of response is based on the concept of power density. Research has shown that power density is proportional to the square of field intensity. This particular antenna, therefore, produces an electric field whose power density is proportional to the square of cosecant θ.

Recalling from a review of Basic Electronics that RF signal strength is inversely proportional to the square of the distance from the source, note that a balance of signal loss against signal gain is utilized in this antenna. As the slant range r (fig. 8-10 (A)) increases, θ decreases and $\csc\theta$ increases. The signal strength (power density) is inversely proportional to the square of $h \csc\theta$ because the wave is RF energy; at the same time, the signal strength is directly proportional to the square of $\csc\theta$ because of the antenna design. (Assume that h is constant.) The result is a net change of zero (theoretically) in the signal strength up to the maximum range of the transmitter. The antenna which produces this result is called the cosecant-squared antenna.

Figure 8-10 (B) shows the special paraboloid reflector in which the top portion is bent forward to produce the cosecant-squared pattern; also shown is the pattern itself. Notice that this antenna produces a field of constant signal strength (bounded by the dotted line at ground level (line XY)) over a broad range of values of θ.

This same type of antenna is also used (in an inverted position) on the land based and shipboard systems for obtaining equal indications from aircraft at equal altitudes but different ranges.

TYPICAL ANTENNA ASSEMBLY

Thus far, types and characteristics of radar antennas used in aviation fire control equipments have been discussed. It should be obvious that

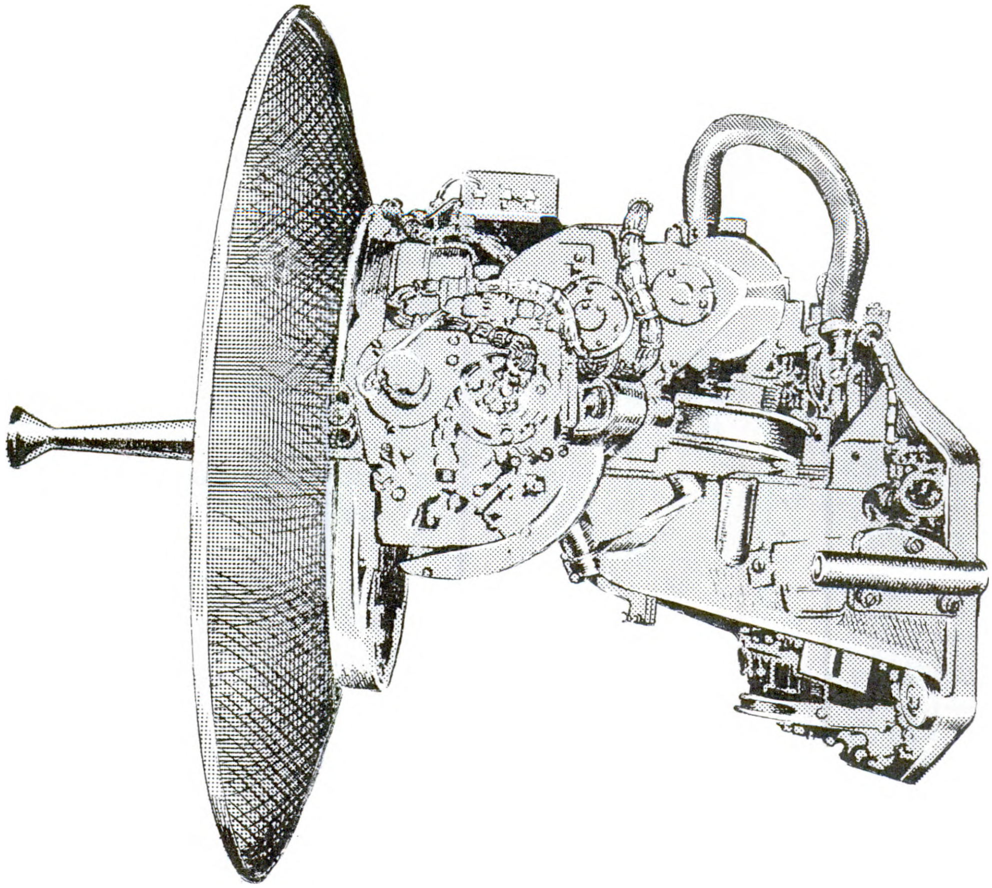


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Figure 8-11. –Typical antenna assembly.

one equipment cannot utilize all the features previously discussed.

Figure 8-11 is an illustration of a typical parabolic reflector type antenna found in an intercept type fire control system.

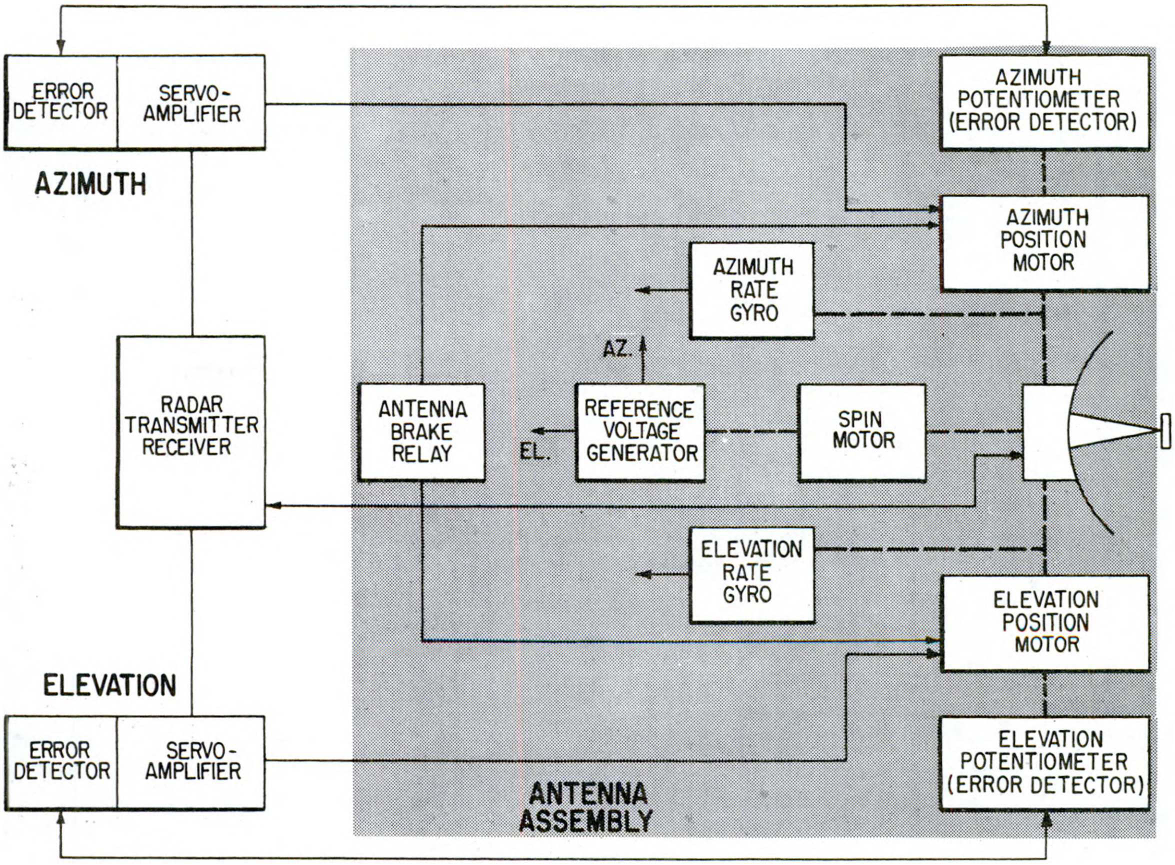
A functional block diagram of the antenna assembly is shown in figure 8-12. It should be noted that the azimuth and elevation servocontrol circuits and the radar transmitter/receiver are shown in the illustration, but are not a part of the antenna assembly.

For convenience of discussion, the antenna assembly will be divided as follows:

1. Antenna radiator and reflector.
2. Spin motor and reference generator.
3. Azimuth positioning channel.
4. Elevation positioning channel.
5. Azimuth rate gyro.
6. Elevation rate gyro.
7. Antenna brake circuit.
8. Antenna stops and limit controls.

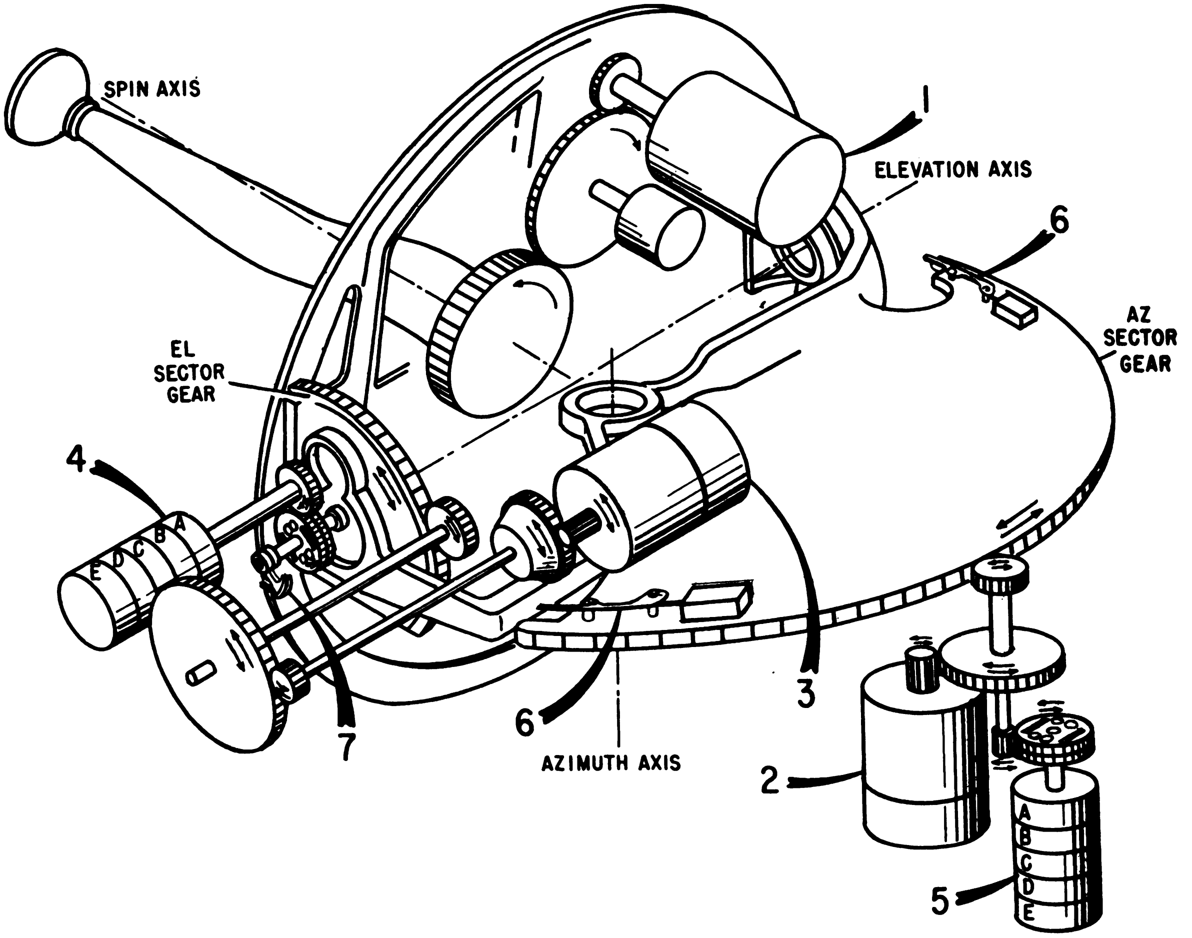
The transmitted pulses from the radar's transmitter are radiated from the feedhorn into the antenna reflector. Reflections of the transmitted pulses from the parabolic antenna reflector form a narrow beam of transmitted energy. Reflections from targets within the beam are intercepted by the antenna reflector, focused at the feedhorn, and propagated through the waveguide to the receiver.

The spin motor (1, fig. 8-13) which drives the feedhorn is a 28-volt d-c motor with an adjustable centrifugal governor that maintains its speed at 12,000 rpm. The feedhorn is located slightly to one side of the center axis of the reflector and is rotated at 50 revolutions per second (rps) to form a conical beam.



AQ. 138

Figure 8-12. –Functional block diagram of antenna assembly.



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1. Spin motor.
2. Azimuth positioning motor and gear train.
3. Elevation positioning motor and gear train.
4. Elevation positioning potentiometer.
5. Azimuth positioning potentiometer.
6. Azimuth cams and limit switches.
7. Elevation cam.

Figure 8-13. –Antenna gear train schematic diagram.

The spin motor also drives a 2-phase, 50-Hz reference generator (not shown) which is used to provide a reference voltage for both the azimuth and elevation control channels in the automatic track mode of operation. The spin generator normally utilizes a permanent magnet rotor which induces a voltage in each of the output windings as the magnetic field is rotated.

The azimuth positioning channel consists of a positioning motor (2) and a gear train, and an azimuth servocontrol circuit. The azimuth motor is a 115-volt, 400-Hz, 2-phase, a-c induction motor which rotates at a maximum of 6,000 rpm. The motor is coupled to the antenna through a 300 to 1 speed reduction gearbox.

Each of the drive gearboxes contains precision gears with minimum backlash. A high degree of precision is required to obtain angular data free from the spurious harmonics that would be injected into the data voltages (especially the angular rate voltages) if excessive backlash were present.

It should be noted that the azimuth potentiometer (5) is also mechanically coupled to the positioning motor through a gear train. Although the azimuth potentiometer is located physically on the antenna assembly, one section of it is part of the antenna position error detector circuit during search mode and manual antenna control.

Antenna servo control circuits are discussed in chapter 8 of Aviation Fire Control Technician 3 & 2, NavPers 10387, and are not discussed in this manual. It is suggested that this material be reviewed to insure a thorough understanding of this manual.

The elevation positioning channel is similar to the azimuth channel except for slight differences in the gear train arrangement. The elevation motor (3) drives the gear train which positions the antenna in elevation and the elevation potentiometer (4). Some antenna systems may also employ resolvers which are mechanically coupled to the azimuth and elevation drive mechanism. These resolvers furnish additional antenna positioning information to the fire control computer.

The azimuth and elevation rate gyros are used to detect and supply the computer the rate of change in azimuth and elevation data. Rate gyros of the type employed are discussed in chapter 10 of Aviation Fire Control Technician 3 & 2, and should also be reviewed.

The antenna brake circuit functions to stabilize the antenna when the equipment is in standby or turned off. It is accomplished by passing a direct current through one of the stator windings of each antenna positioning motor. When the equipment is placed in operation, the brake relay (fig. 8-12) disconnects the d-c source and applies the a-c source.

The extent of antenna scan in both azimuth and elevation is controlled by adjustable cams and limit switches. Bumpers are also provided just beyond the scan limit as protection against overtravel. The azimuth cams and limit switches (6, fig. 8-13) control the azimuth limits of the antenna system discussed in this chapter. The elevation cam (7) is shown, but the limit switch is hidden from view.

MAINTENANCE

The maintenance discussions thus far in this manual have been limited in scope because the alinement and adjustment of components and units of a radar set are interdependent on each other. The same is true with an antenna assembly and many of the antenna alinement adjustments are accomplished during the performance of complete system checks. However, some of the preventive maintenance procedures peculiar to antenna are discussed briefly.

ANTENNA LIMITS

The antenna scan limit bumpers are normally fixed and require no adjustments. The positions of the azimuth cams and limit switches are normally specified in the Service Instructions Manual. For example, the specifications may require the switches to actuate at a setting of 52° plus or minus 2° on each side of center. The steps to follow in setting the switches may vary with each antenna system.

BORESIGHTING

There are several phases to the boresighting procedure. The details of the procedure will usually vary from one fire control system installation to another. Therefore, the applicable Service Instruction Manual should always be consulted for specific procedures to be followed. The accurate and effective delivery of aircraft firepower to a selected target is as dependent on accurate boresighting as on the proper operation of the related equipment. Unless accuracy is maintained at a maximum, the expense of the equipment involved is not justified.

The purpose of boresighting is to establish a specific relationship between the aircraft armament datum line (ADL) and the antenna RF axis, the optical axis, the gun bore, the optical sight unit, and the rocket or missle launcher. Any adjustment required by the guns or launchers will usually be made by the Aviation Ordnanceman.

The boresighting procedure for purposes of this manual is carried out in two-phases–electrical boresighting and harmonization. Electrical boresighting is the procedure used in bringing the radar antenna's RF axis into a parallel relationship with its optical axis. This procedure must be carried out before the harmonization procedure.

Harmonization is the procedure for bringing the radar antenna's optical axis into a parallel relationship with the aircraft armament datum line. Harmonization also extends to the adjustment of the guns and optical sight unit.

The equipment required to carry out boresighting procedures will vary from one installation to another. However, a boresight board and a telescopic boresight kit with associated fixtures will normally be required in all situations. In any case, the applicable Service Instructions Manual should always be consulted for specifications pertaining to these items as well as other test sets and equipment required for boresighting.

Electrical boresighting will require that RF energy be radiated. However, in most aviation fire control radars satisfactory harmonization can be accomplished without radiation, provided the antenna optical axis is in proper agreement with the RF axis of the antenna. Once accomplished, the electrical boresight should remain valid as long as no portion of the antenna structure is damaged, replaced, repaired, or the adjustments disturbed. The periodic inspections required for preventive maintenance will usually require that both electrical boresight and harmonization procedures be performed.

LUBRICATION

Lubrication of the antenna should be performed in accordance with specifications found in the applicable Service Instructions Manual. The specified lubricant will also be indicated in the same publication. The antenna assembly is the only part of a radar set that will normally require lubrication. It should be lubricated in accordance with instructions during the periodic inspections. Table 8-1 is a typical lubrication table for an antenna assembly found in aviation fire control equipment.

MONOPULSE TECHNIQUES

The purpose of an airborne fire control radar system is to supply to a computer (human or electronic) accurate range and pointing angle (directional) information concerning a target for use in the firing of the aircraft's armament. While precise measurement of the range can be made by timing the radar echo, the pointing accuracy of a simple radar can be basically no better than the beam width of the antenna. The antenna beam width is approximately λ/D (radius, where λ is the wavelength of the radiation and D is the antenna width or, for a paraboloid, the diameter). As the beam width becomes narrower, the pointing angle accuracy will improve. Since a beam width of several degrees is typical of airborne fire control radar antennas, additional features are required in the system to provide the desired pointing accuracy of a few milliradians (which are only one or two hundreths of the beam width). The basic method of obtaining the higher accuracy may be termed "lobe comparison," and the numerous variations of the method may be classified as "simultaneous" and "time sequential."

SIMULTANEOUS LOBE COMPARISON SYSTEMS (MONOPULSE)

In the simultaneous lobe comparison system, complete target position information is obtained on each pulse of the radar set. For this reason the system is commonly called monopulse.

From the target echo the monopulse antenna derives signals which give the range of the target and its direction relative to the axis of the antenna. There are three waveguide terminals, one for the transmit and range signal reception, and one each for azimuth and elevation error signal reception (fig. 8-14). The RF signals which appear at these three terminals are used to provide the d-c pointing error voltages. The signals picked up by the feed apertures are combined in such a manner that their sums and differences are obtained. Two types of radiation patterns result in each plane, a sum pattern (fig. 8-15) and a difference pattern (fig. 8-16). The sum signal is used for search operations and gives the range of the target. The sum pattern, obtained by the inphase addition of the echo signal received by the two apertures in one plane, is characterized by a main lobe of considerable directivity along the antenna axis. The difference pattern for any one plane is obtained from the difference between the echo signal as received by each of the apertures in that plane. From these signals the azimuth and elevation error signals are obtained by comparison of the difference signals with the sum signal in each plane. The difference pattern has two main lobes and a null on axis. The main lobes are symmetrical and equal for a difference pattern plotted in power; however, the fields associated with the two lobes are 180° out of phase; and the RF voltage appearing at the antenna error channel terminals varies with angle, as in figure 8-17. (This description assumes perfect symmetry in the antenna.)

Table 8-1. –Antenna system lubrication chart

Item No.	Lubrication point	Method of application	Number of places	Lubrication interval (hours)
1	Feedhorn spin bearings.	Remove feedhorn assembly and pack.	2	200
2	Spin drive gears.	Remove motor B6203 and apply liberal quantity of lubricant to exposed gears. Revolve gears to get complete coverage.	3	200
3	Spin air seal.	Remove feedhorn and apply lubricant to air seal.	1	200
4	Azimuth sector gear.	Unhook tape seal, clean, and brush lubricant on lightly.	1	200
5	Azimuth gearbox gears.	Remove access cover and brush lubricant on exposed gears. Revolve gears to get complete coverage.	4	200
6	Elevation sector gear.	Unhook tape seal, clean, and brush lubricant on lightly.	1	200
7	Elevation gearbox gears.	Remove access plug button and brush lubricant on exposed gears. Revolve gears to get complete coverage.	4	200
8	Azimuth gearbox bearings.	Pack half full.	2	1,000
9	Azimuth axis bearings.	Pack half full.	2	1,000
10	Azimuth synchro and resolver gears.	Brush lubricant on exposed gears to get complete coverage.	5	1,000
11	Elevation gearbox bearings.	Pack half full.	4	1,000
12	Elevation axis bearing.	Pack half full.	2	1,000
13	Elevation synchro and resolver gears.	Brush lubricant on exposed gears. Revolve gears to get complete coverage.	3	1,000

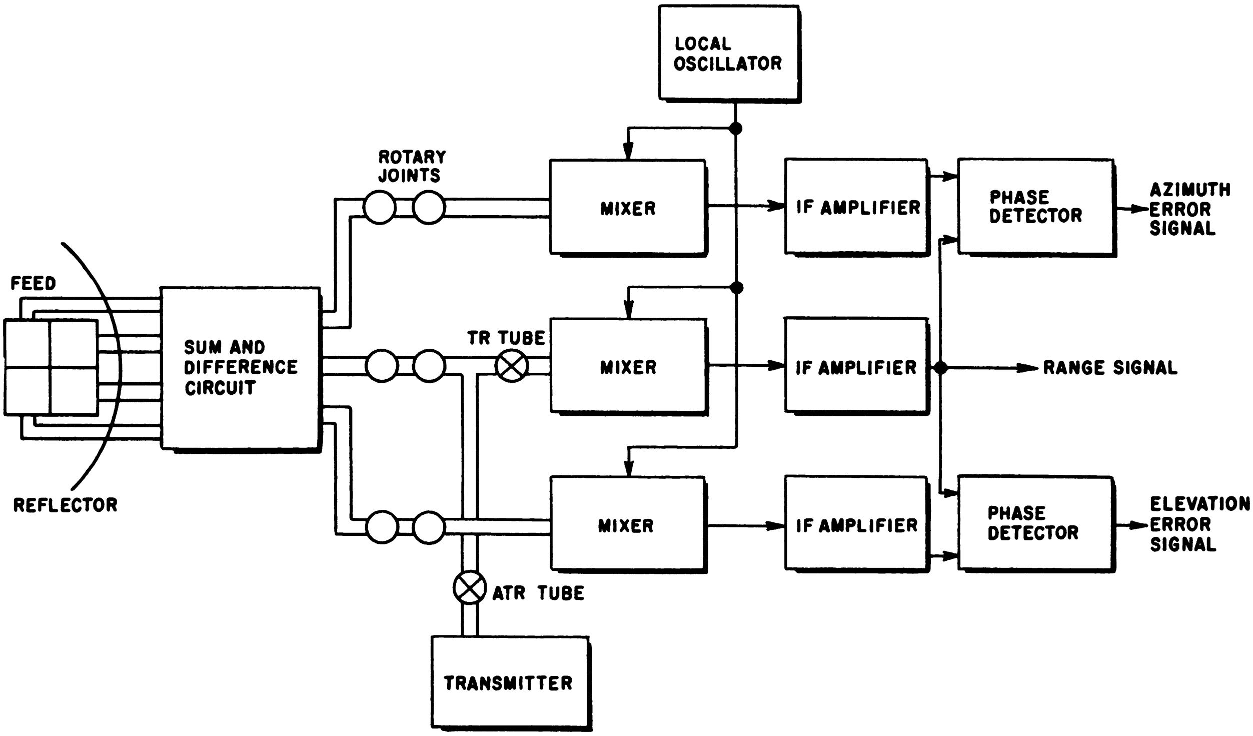

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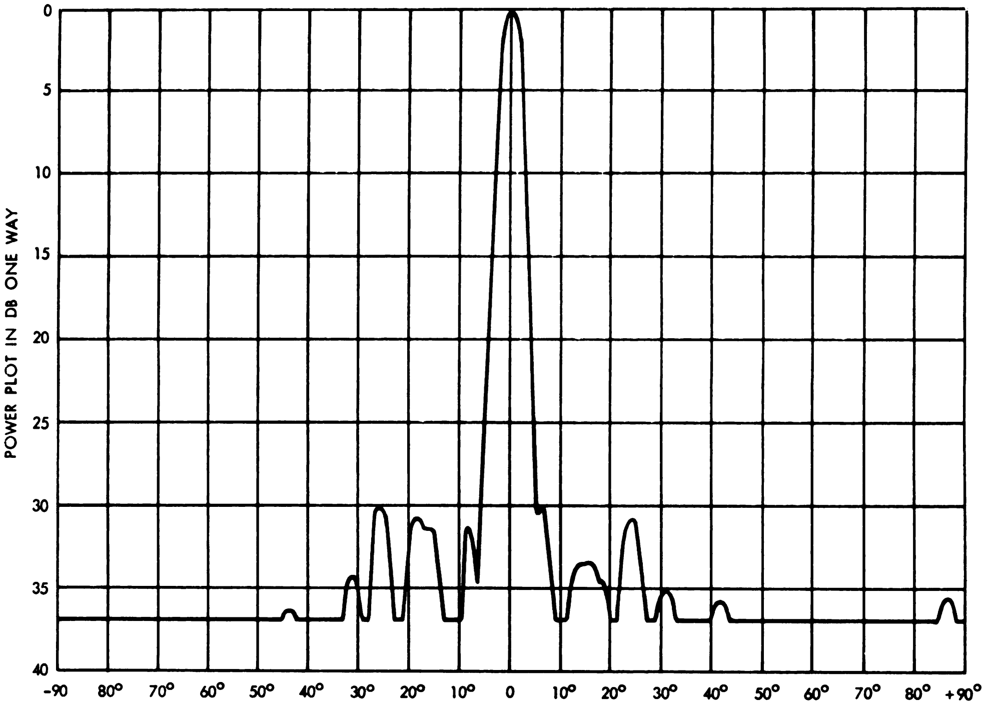
Figure 8-14.—Three-channel monopulse radar system.



AQ. 141

Figure 8-15.—Typical sum radiation pattern of monopulse antenna.

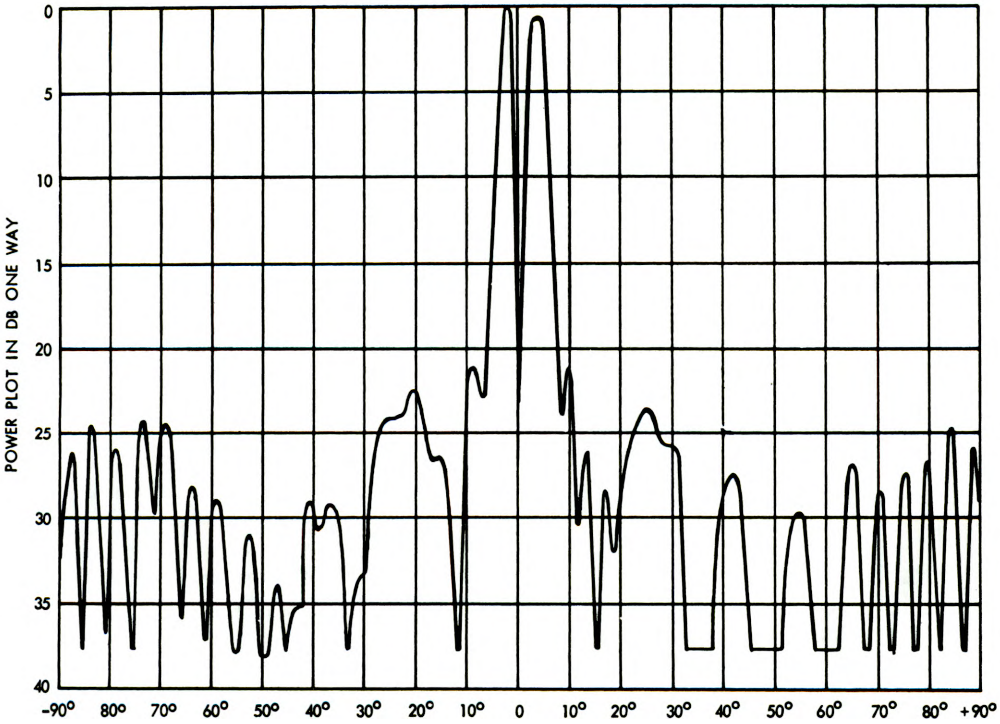


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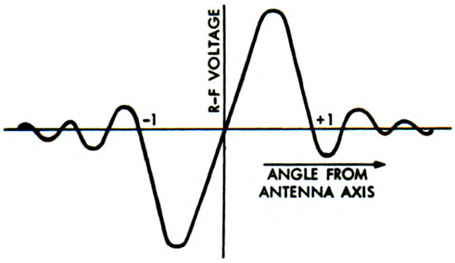
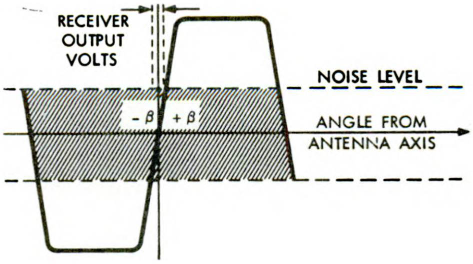
Figure 8-16.–Typical difference radiation pattern of monopulse antenna.



AQ. 143

Figure 8-17.–RF voltage at error terminal of antenna.

The nonlinear response of the radar receiver with its automatic gain control modifies the error characteristic so that the final d-c error signal which controls the antenna pointing servos varies somewhat with pointing error (fig. 8-18). The pointing accuracy of the system is dependent on the steepness of the overall characteristic near zero. If the noise in the system has an amplitude as shown in figure 8-18, small error signals will be masked by the noise; and the antenna will point erratically between angles +β and -β. A steeper characteristic decreases this error. The steepness of the overall characteristic is proportional to the slope of the antenna difference voltage characteristic, and it is desirable to design the antenna to maximize this slope. The error characteristic is an intrinsic feature of the antenna and depends on the aperture illumination.



AQ. 144

Figure 8-18.–D-c error voltage at servo input.

The relative level of the noise (fig. 8-18) depends on the signal to noise ratio, so that the signal to noise ratio in the final error signal output determines the pointing accuracy of the system. The overall signal to noise ratio is determined by the RF signal at the mixer, and this signal depends on both the antenna transmitting and the error receiving characteristics. The received wave is a reflection of the transmitted wave, and is proportional to the gain of the antenna transmit channel. Thus, a true measure of the antenna error sensitivity must be a function not only of the slope of the antenna error voltage characteristic, but also of the antenna transmit channel gain.

Monopulse systems are usually classified as phase comparison, amplitude comparison, or phase amplitude comparison, depending on the characteristics of the antenna.

Phase Comparison System

In the phase comparison type, there are always two or more apertures in each plane that are fed independently. The target echoes picked up by the two apertures are equal in amplitude because the apertures are oriented together; but when the target is not on the axis of the antenna, the echoes picked up by the apertures differ in phase, since one aperture of the antenna is closer to the target than the other.

Amplitude Comparison System

In this monopulse system, at least two components of the feed aperture are alined in each plane and are generally smaller than those of the phase comparison type (since there is no need for size or geometric separation to pick up several phases of the incident wave). The target echo excites each aperture differently, and pointing information is derived from the resulting amplitude difference.

Phase Amplitude Comparison System

In this system (a combination of the other two types), error signals are obtained by phase comparison in one plane and by amplitude comparison in the other.

MONOPULSE SYSTEM ERRORS

In any of the monopulse antenna systems, pointing errors can arise in two distinct ways. Phase or amplitude discrepancies in the received signals, which result from asymmetries in the feed structure or from radome refraction, give rise to pointing errors. A second contribution to the pointing error arises from the combined effects of the radome error and the asymmetries and of phase errors between the parallel receiver channels which are required in a monopulse system. Signal errors in phase or amplitude are always present to some degree, since the feed structure and the radome cannot be perfect. Similarly, phase discrepancies between receiver channels will generally be present. For satisfactory system performance, however, it is mandatory that both sources of pointing error be minimized; in fact, the design of IF amplifiers with satisfactory phase characteristics over a large dynamic range constitutes one of the major problems in a monopulse system.

A constant phase distortion causes the antenna pointing angle to deviate a fixed distance as long as the frequency is constant; however, at a constant frequency, variations will occur in the errors introduced by amplitude distortions in combination with phase errors between receiver channels.

Some shift in itself is not detrimental (as long as the frequency is constant), since it merely defines a new pointing axis. The position of the new axis, however, varies with frequency, and it is the shift of the pointing axis with frequency which is important. The phase error between feeds may result from structural asymmetries in the feed, or it can result from radome effects as well. Since the phase errors caused by the radome vary as the antenna scans, a variable shift in pointing axis then results, even with a fixed frequency. The major sources of error for both phase and amplitude comparison monopulse systems are in the feed system as follows:

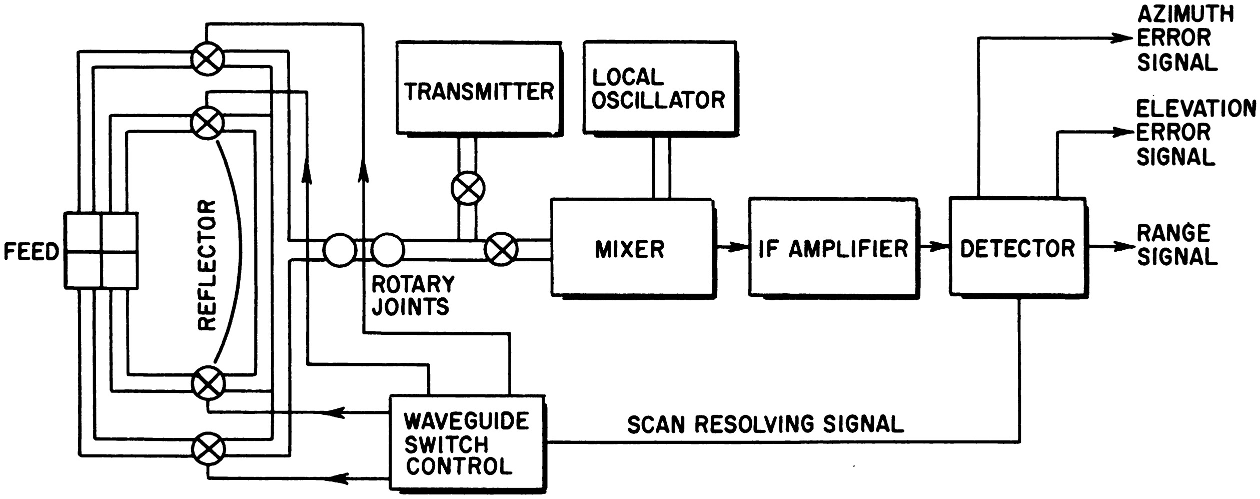
1. For the phase comparison system the primary errors are phase errors, and secondary errors are amplitude errors (in front of the sum and difference circuits).
2. In the amplitude comparison systems, the primary errors are amplitude errors and secondary errors are phase errors.
3. Both systems experience phase errors between receiver channels.

TIME SEQUENTIAL LOBE COMPARISON SYSTEMS

The time sequential classification includes conical scan and sequential lobing systems.

Conical scanning was discussed previously and is compared to sequential lobing in the following paragraphs.

A time sequential radar system which provides only four positions in rotation is the "sequential lobing" type (fig. 8-19). The sequential lobing antenna has four feed apertures. By means of waveguide switches, these four apertures may be used individually in sequence to provide without motion the same result as conical scan but at much higher scanning speeds than are possible mechanically. The construction of sequential lobe comparison systems inherently provides a further advantage over conical scan: all four apertures transmit simultaneously; only one receives at a time. In this way the peak of the transmitted beam is on the crossover axis, giving a larger target reflection than in the conical scan system, in which the beam peak is displaced from the crossover axis.



AQ. 145

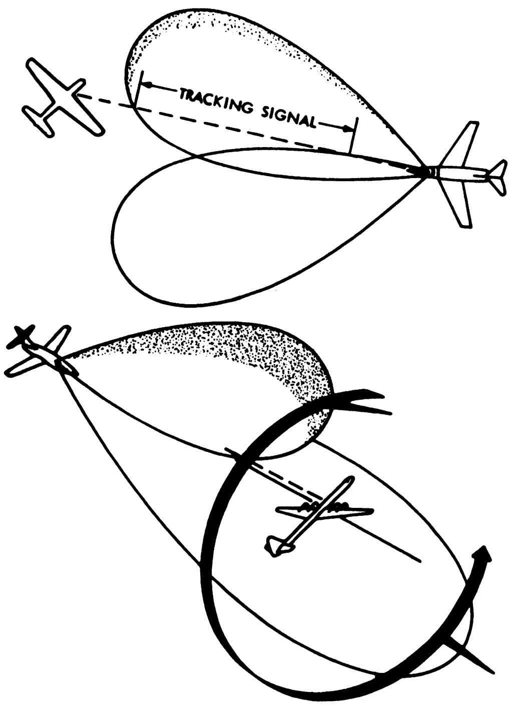
Figure 8-19.–Sequential lobing radar system.

COMPARISON OF MONOPULSE WITH TIME SEQUENTIAL SYSTEMS

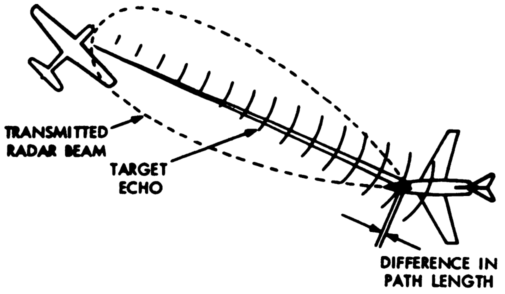
The essential characteristic of both the conical scan and sequential lobing systems is that they measure echoes received at different times. (See fig. 8-20.) The monopulse systems, on the other hand, derive all range and pointing information from each single pulse echo (figs. 8-21 and 8-22). The classification of fire control antennas as simultaneous lobe comparison or time sequential lobe comparison is made because a significant advantage of monopulse appears in this connection. Since time sequential lobing entails comparison of two echoes separated in time, changes in the reflective properties (scintillation) of the target or fluctuation in transmitted power can cause false error signals. For the same reason, the sequential system is vulnerable to certain types of jamming. The higher scan speed obtainable by sequential lobing with waveguide switches instead of mechanical motion reduces but does not eliminate these spurious error signals. The monopulse, deriving complete information from each pulse, is not susceptible to these effects.

An advantage monopulse enjoys over conical scan, although not necessarily over sequential lobing, is a greater overall angular sensitivity, because the target is tracked at the peak of the transmitted beam. In conical scan, the target is tracked at the beam crossover, which is usually near the half power point. The voltage sensitivity is essentially equal for both monopulse and conical scan antennas, but the overall angular sensitivity is less for the conical scan because of the weaker echo. The sequential lobing antenna can be designed to track the target at the peak of the transmitted beam and can avoid the power loss inherent in the conical scan. However, with a sequential lobing system, the RF noise produced in the received signal by existing lobe switching tubes is a major disadvantage.

In a conical scan antenna, input impedance varies with rotation of the scanning mechanism.



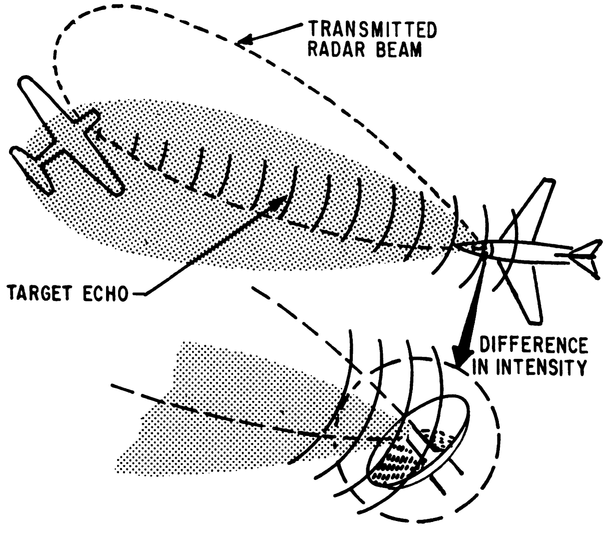
AQ. 146
Figure 8-20.—Typical fire control antenna beam—conical scan.



AQ. 147
Figure 8-21.—Typical fire control antenna beam—phase comparison monopulse.

The changing load presented to the magnetron causes fluctuations both in frequency and in power. A unilateral device, such as a ferrite gyrator, is necessary to overcome this problem. The input impedance of a monopulse antenna remains essentially constant, since there are no moving elements except the rotary joints.

Mechanically, the monopulse antenna is somewhat more complex than the conical scan type, but there are no moving parts in the antenna proper. Since the antenna feed has no bearings or drive mechanisms, the monopulse system is less subject to mechanical breakdown. Pressurization may be easier. However, the additional rotary joints which are necessary if receiver components are not mounted on the antenna are an added complexity. Although monopulse antennas vary in weight from type to type, they compare favorably with the conical scan when the weight of the spin motor and resolver is considered.



AQ. 148
Figure 8-22.—Typical fire control antenna beam—amplitude comparison monopulse.

In sequential lobe comparison and conical scan systems, the pointing error information appears as an amplitude modulation of the received signal. Only one channel, involving one rotary joint in each gimbal axis, one mixer, and one IF amplifier, is necessary to carry this information. In a sense this single channel is time-shared. The monopulse system, on the other hand, deriving complete pointing information from each pulse echo, cannot time-share one channel, but requires two or three. The multiplicity of receiver components and rotary joints adds weight and complexity and tends to decrease the electrical reliability. The additional rotary joints may be avoided by mounting some receiver components on the antenna, although this arrangement adds inertia to the antenna and requires the use of flexible cables. The decision whether to suffer the additional rotary joints or to avoid them by placing receiver components on the antenna is an involved one which must be reached for each particular application.

CHAPTER 9

RADAR RECEIVERS

In the previous chapter the importance of developing an extremely high powered pulse by the transmitter was discussed. Although the high power pulses are radiated in a narrow beam, only a small part of the radiated energy actually strikes a distant target. Since the energy striking the target is reflected or reradiated over a wide angle, only a very small part of the transmitted energy is returned to the radar's antenna. Thus, the function of the radar receiver is to receive the weak target echoes from the antenna and amplify them sufficiently to provide the indicator with the desired target information. Consequently, the weaker the signal which the receiver can use, the greater the effective range of the radar set.

RECEIVER REQUIREMENTS

Before considering the details of operation of the radar receiver, some of the requirements it must fulfill are reviewed.

SIGNAL TO NOISE RATIO

The name commonly given to small random fluctuating voltages present in the input stages of radar receivers is noise. In a radar set the noise voltages cause unwanted deflections of the electron beam in electrostatic deflection systems, and erratic fluctuations in intensity of the beam in intensity modulated systems. (The causes of noise are discussed later in this chapter.)

Though noise voltages are highly undesirable in radar receivers, they cannot be completely avoided. Although receivers have been built having greater input sensitivity, their operating limit is determined by the noise level within the receiver. When the signal voltage level falls below the noise voltage level, the returning signals are obscured by noise on the indicator. A further increase in amplification is useless because the noise and signal voltages are both amplified equally. Therefore, the highest obtainable signal to noise ratio is desired in the input stage of a radar receiver in order to make the signal at the indicator discernible from the noise. The loss of small amounts of power in the echo signal or the addition of an equally small noise power in the input stage may reduce the maximum range of the radar set as much as the loss of large amounts of power from the transmitter. Thus, the sensitivity of a radar receiver is measured by the smallest input signal that can produce an output signal discernible against the noise background on the indicator.

NOISE

Before considering the causes of receiver noise, its effect will be discussed. The lack of low noise RF amplifiers capable of successfully operating in the microwave region has resulted in the RF signal being converted directly to an IF signal in a crystal mixer before it is amplified. Thus, weak incoming signals could be lost in the noise of the mixer and input circuit of the first amplifier stage.

Not only must the noise level in a radar receiver be kept low, but every effort must be made to minimize attenuation of the received signal before it reaches the amplifier stages. The most common causes of noise in radar receivers are generated by the following:

1. Thermal agitation within electronic components–varies directly with temperature.
2. Shot noise–vacuum tube noise resulting from the shot effect of electrons leaving the cathode with random changes in velocity, which produce random changes in plate current.
3. Induced grid noise (vacuum tube), which results from the electrons passing by the control grid when flowing from cathode to plate.

Noise generated or induced in the mixer or other input stages of the receiver is most critical since it will receive equal amplification as the input signal throughout the remainder of the receiver. Therefore, the overall signal to noise ratio of a radar receiver will be largley determined by the noise introduced in the first stage.

BANDPASS

The input to the receiver amplifiers consists of minute rectangular pulses of RF energy. In addition to being able to pass the carrier (intermediate frequency), the amplifying stages must be capable of amplifying the modulation frequency. It should be recalled that a perfectly square wave consists of a fundamental frequency sine wave plus an infinite number of odd harmonics. Thus, to pass signals of this broad frequency range, radar receivers use amplifiers that have a relatively wide bandpass characteristic. Improper alinement of the receiver's amplifiers may cause distortion and loss of gain to target, resulting in poor target definition, reduction of range, and reduced accuracy of range measurements. All are highly important in fire control radars.

TUNING

Radar transmitters (magnetrons) used in most aviation fire control equipment have relatively poor frequency stability. As the radar antenna rotates, the antenna impedance may change. Thus, the load presented to the transmitter changes, and the output frequency of the magnetron changes. Other inherent factors cause considerable magnetron frequency shift over longer times. When the output frequency of the magnetron changes, the receiver must be retuned automatically if it is to receive the reflected echoes. Therefore, radar receivers must have the necessary circuitry to provide for automatic tuning–commonly called automatic frequency control (AFC).

FUNCTIONAL OPERATION

Radar receivers found in aviation fire control equipment use superheterodyne circuits of the single-conversion type (single intermediate frequency). Superheterodyne receivers are discussed in detail in chapter 14 of Basic Electronics, NavPers 10087-B, and should be studied prior to continuing in this chapter. Although the receiver circuits discussed are primarily broadcast and communication receivers, their basic principles of operation are applicable to radar receivers.

Radar receivers differ from communication receivers in the following respects:

1. Radar receivers must detect received signals of approximately the same amplitude as the random noise generated by resistors, vacuum tubes, and other electronic components in the input stage.
2. Radar receivers must be much more sensitive than communication receivers, in which static limits the smallest signal that can be heard.
3. Radar receivers must receive very short pulses of RF power reflected from distant targets.

The pulses returned to a radar receiver have widely varying amplitudes and distorted waveshapes. To determine target range accurately, pulse wavefronts must rise very rapidly. To reproduce these rapidly changing signals, the radar receiver bandwidth must be very wide.

The block diagram illustrated in figure 9-1 is representative of a typical superheterodyne type radar receiver which is found in most aviation fire control radar sets.

Referring to the block diagram, RF energy from the antenna is fed to the mixer. Crystal mixers are used as the first stage in most radar receivers because of their high signal to noise ratio and simplicity. One type of crystal mixer is discussed in chapter 12 of Aviation Fire Control Technician 3 & 2, NavPers 10387. Other types are considered later in this chapter.

The local oscillator couples its output through the waveguide to the mixer. The local oscillator, as used in most microwave receivers, is discussed in Aviation Fire Control Technician 3 & 2 and is discussed in greater detail later in this chapter. The heterodyne action produces a difference frequency which is used as the intermediate frequency. This difference frequency may range from 30 to 100 MHz, but in most aviation fire control receivers the IF is either 30 or 60 MHz.

The IF amplifier consists of a preamplifier and an IF strip. The preamplifier is physically located near the crystal detector to prevent loss or attenuation of the signal before it can be amplified. The input circuit of the first preamplifier stage is tuned to the intermediate frequency and bypasses all other unwanted frequencies to ground. (NOTE: It is in this section of the receiver where noise generation must be rigidly controlled.) The preamplifier normally consists of at least two stages of amplification, the first of which may be a cascade type. Its output is fed to the main amplifier which is normally referred to as the IF strip.

The IF strip consists of several stages of double-tuned IF amplifiers. They are double tuned to broaden the bandpass of the receiver for better fidelity. The gain of the IF amplifier is normally between 10^6 and 10^{12}, and can be varied by altering either the control grid bias

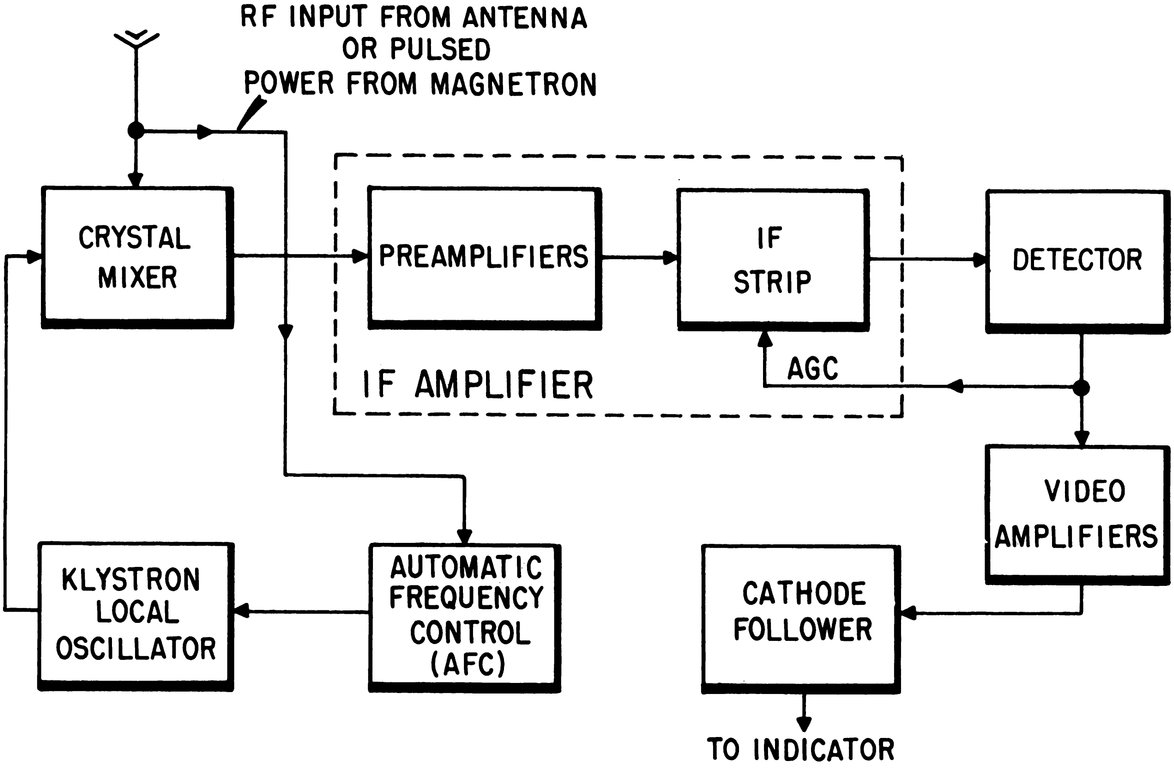


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Figure 9-1.–Block diagram of a radar receiver.

or the screen voltage of one or more stages.

The greatly amplified signal is then fed to the detector, usually a conventional diode detector, where the video signal is removed from the IF carrier. The detector filters used in most aviation fire control radar receivers must be a long RC to the IF frequency and a short RC to the video envelope. Thus, the intermediate frequency is shorted to ground and the detected video pulses are passed to the next stage.

The video amplifier receives the detected pulses and amplifies them to the magnitude required to operate the indicator. The input to the video amplifier is in the form of rectangular pulses which are made up of an infinite number of odd harmonics. Therefore, the video amplifiers must be designed for a wide bandpass in order to amplify the principal harmonics and preserve the shape of the input waveform.

The output from the video amplifier is fed to the video output cathode follower. The cathode follower is used as an impedance matching device between the video amplifiers and the indicator. It also serves as a power amplifier to drive the indicator. In the case of remotely located indicators, it is also used to match the impedance between the video amplifiers and the interconnecting coaxial cable.

The last block to be discussed in figure 9-1 is the automatic frequency control (AFC) circuit. The AFC circuit is used to automatically adjust the local oscillator frequency so that the radar receiver is always tuned to the radar transmitter frequency. Remember, the loading of a radar transmitter often changes as the transmitting antenna rotates (scans). The frequency of a microwave oscillator is very sensitive to changes in load impedance. Thus, as the transmitting antenna of a microwave radar is rotated, the transmitter frequency changes. If the receiver frequency does not also shift, these frequency changes may be so great that the received signal is outside of the receiver bandpass. In these cases, automatic frequency control is used to automatically track the radar receiver tuning with the transmitter frequency.

Although many different types of automatic frequency control circuits are used in microwave radars, all AFC systems are basically similar in operation. Practically every AFC system has circuits that produce an output voltage proportional to the change in transmitter frequency. This output voltage changes the local oscillator output frequency in such a way that the radar receiver remains tuned to the transmitter frequency.

CONVERTER CIRCUITS

The converter circuits include those circuits which are necessary to convert the returning microwave signal to an intermediate frequency that can be amplified. They are the mixing chamber, the local oscillator, and the crystal detector. Each is discussed in the following paragraphs.

MIXING CHAMBER

The mixing chamber consists of a special section of waveguide construction to provide proper coupling of received RF and local oscillator signals to one or two crystals which terminate the waveguide. Since the crystal rectifiers are nonlinear devices, rectification of these signals results in the formation of the "beat" or "IF" frequency.

LOCAL OSCILLATORS

The local oscillator must be capable of producing an output frequency equal to the transmitter frequency, plus or minus the IF, and must be tunable over a range of several megahertz. In addition, the power output need not be more than 20-50 milliwatts. An excess of power could cause the maximum current of the crystal detector to be exceeded. Because the reflex velocity modulated tube or klystron meets these requirements better than any other type of tube now in production, it is used almost exclusively for local oscillators in microwave radar receivers.

The frequency range of klystrons is from approximately 500 to 50,000 MHz. Klystrons can be used as amplifiers and oscillators both at high power levels and at low power levels. Klystrons, like conventional electron tubes, are manufactured in a wide variety of types and sizes.

Theory of Operation

In the circuit of the reflex klystron (fig. 9-2), note the arrangement of the electrodes and the voltages involved for operation.

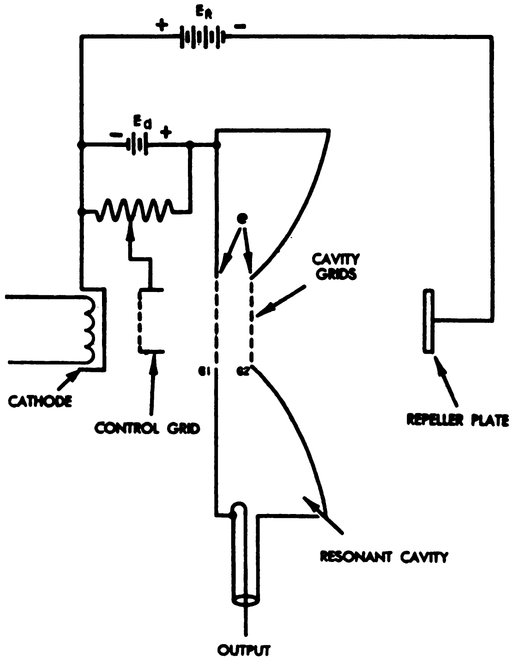

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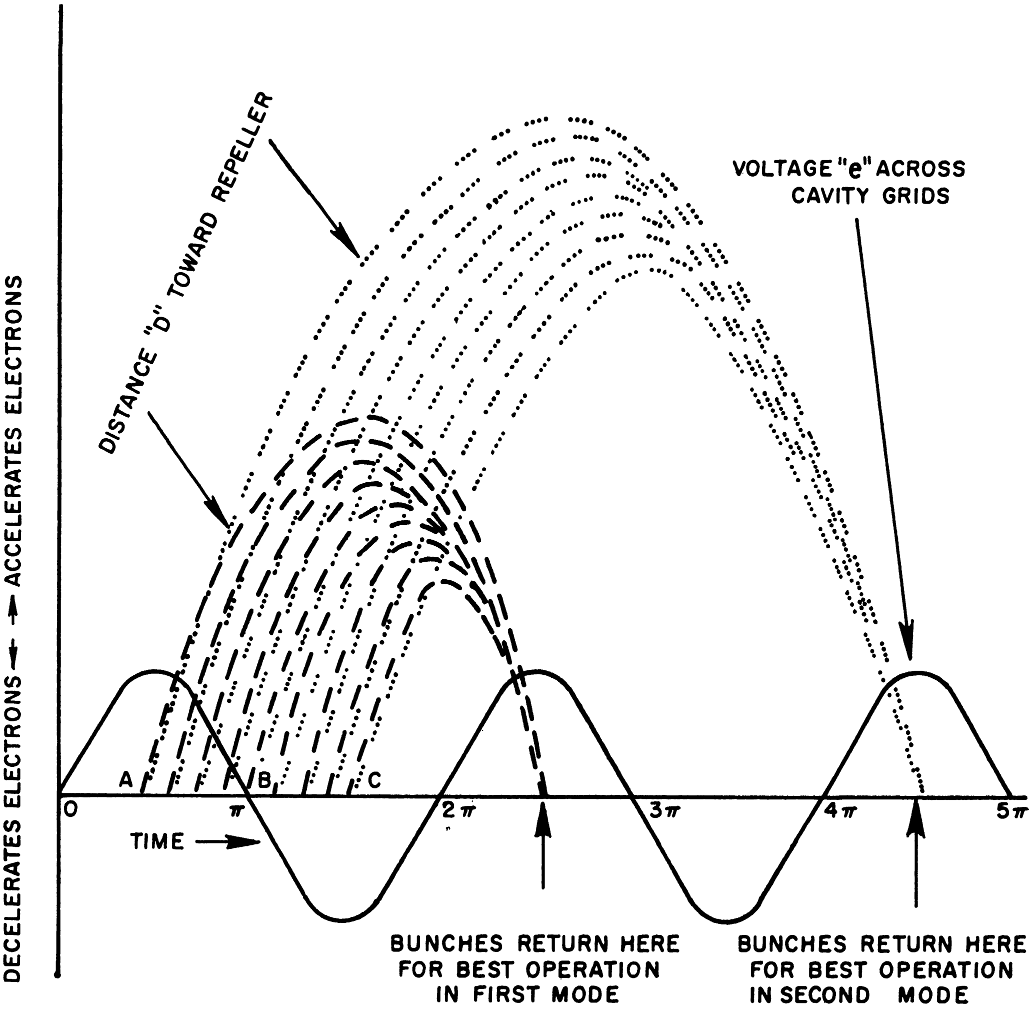
Figure 9-2. –Circuit of a reflex klystron oscillator.

It is important to consider the cause of oscillations in resonant cavities. In most oscillators, oscillations start from some irregularity in current flow, such as a transient that results from voltage being suddenly applied to the tube or from shot effect. With this in mind, assume that the oscillations in the resonant cavities are already taking place. From this assumption examine the source of the energy needed to sustain these oscillations.

With the tank circuit oscillating, a high frequency voltage, e, appears between the two cavity grids. This causes the electric field between these grids to reverse twice during each complete cycle of operation. As the electrons approach these grids, the electron stream is uniform. The time that is required for the electrons to pass through the small distance between the grids is short compared to the period of oscillations. Electrons which enter the space between the grids when e is zero will encounter no a-c electrical field and they will pass through at their initial velocity. The electrons which


DISTANCE "D" TOWARD REPELLER
VOLTAGE "e" ACROSS CAVITY GRIDS
DECELERATES ELECTRONS ← → ACCELERATES ELECTRONS
A
B
C
0
π
2π
3π
4π
5π
TIME →
BUNCHES RETURN HERE FOR BEST OPERATION IN FIRST MODE
BUNCHES RETURN HERE FOR BEST OPERATION IN SECOND MODE

AQ. 151

Figure 9-3. -Bunching action of a reflex klystron.

enter the space when e makes grid G1 positive with respect to grid G2 will encounter a field which tends to accelerate them. The amount of acceleration is a function of e. Electrons entering the space when e is reversed in polarity are decelerated. The change in velocity due to acceleration and deceleration is small in comparison with the original velocity. Those electrons which are accelerated most will travel farther toward the repeller plate before being turned back, while those that are decelerated most will be turned back sooner. Thus it is conceivable that with the proper magnitudes of e, E_a and E_R, electrons returning to the cavity grids will arrive in bunches.

Figure 9-3 shows the position of electrons in the tube at various times during their transit. The zero distance position, taken as the baseline in the graph, is midway between the cavity grids. Electron A, which arrives when G2 is positive, is accelerated and travels farther before being turned back; electron B is unaffected; electron C is decelerated and turns back after a shorter excursion. Hence, in the diagram these electrons and the ones passing through at intermediate times are shown as arriving back at the grids at the same instant of time. This is the ideal situation, but it is not difficult to see that electrons will return to these grids in a stream which varies in intensity at the frequency of the oscillations. Due to this fact, this tube is called a reflex velocity modulated tube because the electrons reverse direction and travel through the interelectrode space twice.

On the return trip the electric fields set up by the voltage e again act upon the electrons. Since they are now traveling from G2 to G1, they will be decelerated if they return when G2 is positive in respect to G1 and accelerated if they arrive when G2 is negative. When an electron is accelerated by an electric field, its kinetic energy increases; this additional energy is taken from the electric field. On the other hand, an electron which is decelerated gives up energy to the electric field. If the bunches of electrons can be made to arrive back when G2 is positive, they will give up energy to the alternating field. For maximum transfer of energy the bunches must arrive when G2 is maximum positive. The question arises as to where this energy originates. Remember that if the electron stream from the cathode is uniform, some electrons are accelerated and some are decelerated on the outbound trip by the electric field of e. On the average, as many electrons absorb energy from the field as give up energy to it. Hence, very little net energy is taken from the oscillating circuit during the bunching process. The average kinetic energy of the electron is that imparted to it by the d-c voltage of E_a. Thus, some of the energy taken from the d-c electric field is transferred to the a-c field to sustain the oscillations. The power output is taken from the klystron with an inductance loop located inside the resonant cavity.

Modes of Operation

It is not necessary that the bunches of electrons return to the grids on the first positive swing of G2. Figure 9-3 indicates that if the bunches arrive on the second positive swing, the net result is the same. The time in transit for the average electron B is 3/4 cycle, 1 3/4 cycles, 2 3/4 cycles, etc. In actual practice there are three or four 'modes" in which it is possible for the reflex velocity modulated tube (klystron) to oscillate. The dark lines in the illustration indicate paths of electrons operating in the first mode while the light lines indicate paths of electrons operating in the second mode. A third mode is possible when the average transit time is 2 3/4 cycles, etc.

The following shows how the transit time is controlled to produce oscillations in the different modes. Since the original velocity of an electron depends on the d-c voltage E_a, and since the distance that the electron travels before turning back and the speed with which it returns depend upon the difference between E_a and E_R, it is possible to adjust the two voltages E_a and E_R for any of the modes. The voltage E_a is usually fixed in magnitude since varying it produces greater initial velocity. This in turn would cause a farther excursion and a greater return velocity. E_R is made variable since it is not feasible to make E_a variable. For operation in the first mode, the round trip must be completed in the shortest time. This is accomplished by making the repeller plate highly negative. For longer periods of interelectrode space travel for higher modes (second mode, etc.), the repeller is made less negative.

Power and amplitude limitations are due to overbunching as well as the usual losses in the oscillatory circuit. Overbunching occurs in the following way. As oscillations build up and e becomes greater, the amount of acceleration and deceleration increases. This causes bunching to occur within a shorter period of time; that is, in a time before the electrons reach the grids on the return trip. This tends to reduce the magnitude of oscillations. In the higher modes of oscillation where the bunches are formed more slowly, the electrons are more susceptible to overbunching. The magnitude of e which results in overbunching is therefore lower and oscillations are limited by this action to a lower amplitude than in the lower modes of operation.

As shown in figure 9-4, the frequency of oscillations in a reflex klystron is variable to a limited degree in any of the modes of operation by means of varying the repeller voltage. When the repeller voltage is varied, it causes a bunch to return a little sooner or a little later than normal. Off resonance, the amplitude of oscillations decreases by an amount which depends on the Q of the cavity. In this tube the tuning range is small in comparison to the frequency of oscillations and varies somewhat from one mode to another, being greatest in the highest mode. This can be explained from the fact that in the highest mode, bunching and debunching take place at a slower rate and that greater variation from the ideal time of return is possible without debunching, causing the amplitude of oscillations to drop below this usable output level. Another way to look at it is that in the highest mode the interval between leaving the grids and returning is greater, and the change

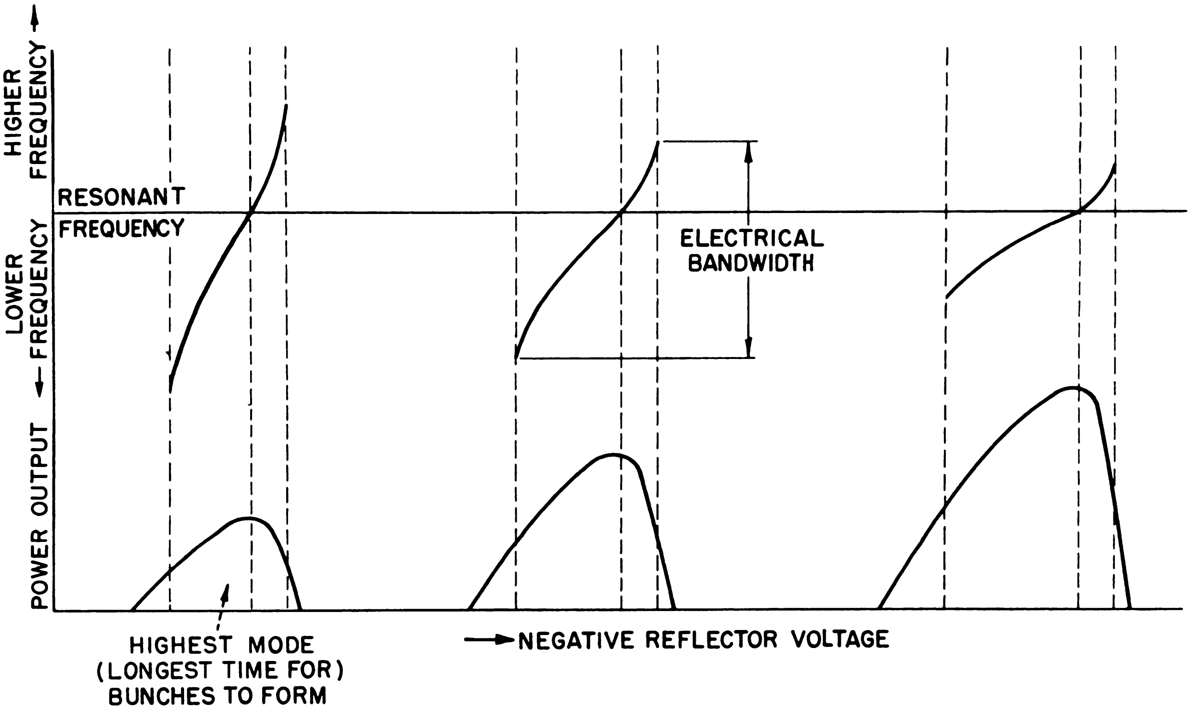


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Figure 9-4. –Power output and frequency versus repeller voltage.

in period represented by a given change in frequency is a smaller portion of the interval. To illustrate, in the third mode the interval before return must be about 2 3/4 cycles. A small change in the period of e would therefore be only 3/4 divided by 2 3/4 or 3/11 as great a portion of the interval as it would if operation were in the first mode where the ideal time interval is 3/4 cycle.

The band of frequencies which can be obtained by varying the repeller voltage lies between the half-power points shown in figure 9-4. This range of frequencies is known as the electrical bandwidth. The output curves of the bandwidth are unsymmetrical about the maximum output points. This results from the fact that if E_R is increased, not only does the bunching voltage e decrease and cause bunches to form at a later time, but the repeller voltage causes a quicker return and the effects of the action add to cause poor bunching at the time the electrons return, resulting in a rapid drop in output on the high side of the hump. At lower voltages, however, even though the bunching voltage e decreases and causes slower bunching, the decreased repeller voltage causes a later return to the grids so that the two effects are counteracting and a greater change in repeller voltage is possible before the output drops below the usable level.

The choice of the point and mode of operation is a compromise of several factors. To begin with, there are three or four modes which have the necessary power output. On the whole, it would seem then that the correct choice would be the highest mode, for it gives the largest tuning range. The highest mode, however, is too sensitive to a change in voltage to be well regulated. Since the humps are unsymmetrical, the point of operation is usually chosen a little below the point of maximum output. This makes it possible to tune above the operating frequency by a greater amount than if the maximum point were used.

In normal operation of a radar set, the reflex klystron is usually tuned automatically. However, this constitutes only a fine adjustment of the klystron. The coarse or primary factor in determination of the klystron's output frequency is the spacing between grids G1 and G2. A mechanical adjustment is provided which physically controls their spacing. Moving the grids closer together increases their capacity and consequently reduces the output frequency. Although this may also reduce the overall size of the resonant cavity, its effect is small as compared to the effect of the change of capacitance.

An adjustment is normally included to permit the setting of the repeller plate at its proper level for the correct mode of operation.

It has been found advisable in the later types of equipment to operate the klystron's local oscillator at a point of maximum output (klystron tuned for maximum crystal current). This is necessary because the noise output of the local oscillator is at a minimum at this point. Maximum output is obtained when the klystron's cavity is resonant to the output frequency. In order to accomplish this in a practical installation utilizing a tunable magnetron, it is necessary that a tuning mechanism be used that will permit remote control of the cavity dimensions of the klystron.

One method of accomplishing this is through the use of a remotely controlled cavity tuning motor. A second and more recent method is thermal tuning, as discussed in chapter 12 of Aviation Fire Control Technician 3 & 2.

CRYSTAL MIXERS

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The name "mixer" refers to a nonlinear device in a superheterodyne receiver in which a continuous local oscillator wave and a modulated RF signal wave are combined to produce an intermediate frequency wave carrying the same modulation as the RF wave. Since there are no vacuum tubes capable of performing this function satisfactorily at radar frequencies, most radar receivers use crystals as mixers.

Before discussing mixing circuits, the crystal will be discussed. A small piece of silicon, galena, or iron pyrite is capable of providing the nonlinear characteristic required for mixing. When a crystal of one of these elements is in contact with a sharp pointed wire, the arrangement will offer a different resistance to current flow from the crystal to the wire than it does from the wire to the crystal. Such a device is called a crystal rectifier or a crystal mixer. (Do not confuse this type of crystal with a piezolelectric crystal which is used to control the frequency of oscillators.)

In radar sets, the crystal is normally silicon and the wire is tungsten. Since some spots on a crystal are more sensitive than others, the point of the tungsten wire ("cat whisker") is placed in contact with the most sensitive part. The contact is made permanent by using a sealing compound and mounting the assembly in a watertight, standard sized cartidge, as shown in figure 9-5.

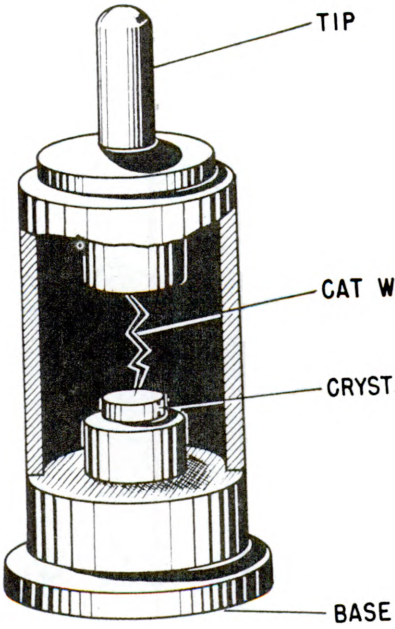

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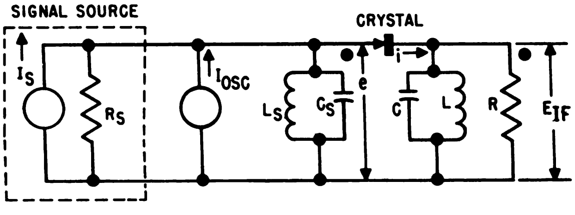
Figure 9-5. –Crystal detector.

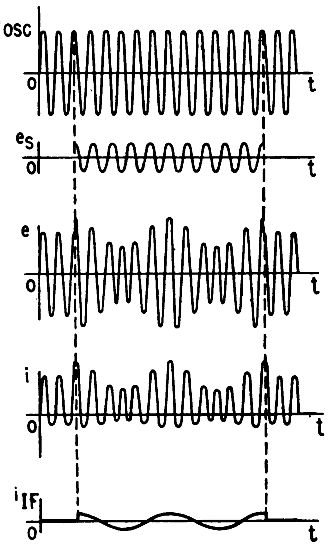
A basic equivalent circuit of a mixer and its associated waveforms are shown in figure 9-6. The signal source and the local oscillator send current through the tuned circuit comprising L_s and C_s. Thus the mixer input voltage e is, as shown in figure 9-6 (B), the sum of a continuous sine wave e_{osc} of local oscillator frequency and a pulse modulated wave e_s of signal frequency. The local oscillator is represented as a current source because it is coupled to the mixer through a high impedance to prevent loss of signal power to the oscillator. The L_sC_s circuit is tuned to the frequency of I_s in order that the largest possible signal voltage may be applied to the mixer. Nevertheless, the local oscillator component of e is ordinarily enormous in comparison with the signal voltage; the oscillator voltage is of the order of a few tenths of a volt, whereas the signal voltage may be less than a microvolt.

Because the crystal conducts current more readily in one direction than the other, the crystal current i is an unsymmetrical wave, as shown in (B) of figure 9-6. During periods between the application of signal pulses, crystal current i comprises a d-c component of e_{osc}. When a signal pulse is applied, additional frequency components appear. In particular, because the average value of i increases and decreases in correspondence with the beat-frequency envelope of e, a current component at the difference frequency of the oscillator and the signal wave appears. By proper adjustment of the oscillator frequency, the difference frequency can be made to equal the desired intermediate frequency of the receiver.

In aviation fire control radar, two general types of crystal mixers are used. They are the single-ended crystal mixer and the balanced crystal mixer, with the balanced mixer predominant. Each will be discussed in detail in the following paragraphs.



(A) BASIC EQUIVALENT CIRCUIT



(B) WAVEFORMS

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Figure 9-6.-Diagram explaining mixing principles.

Single-Ended Crystal Mixer

Most single-ended crystal mixer assemblies found in aviation fire control radars include provisions for an additional or separate mixer for generating IF signals for the automatic frequency control circuit. Figure 9-7 illustrates such an assembly.

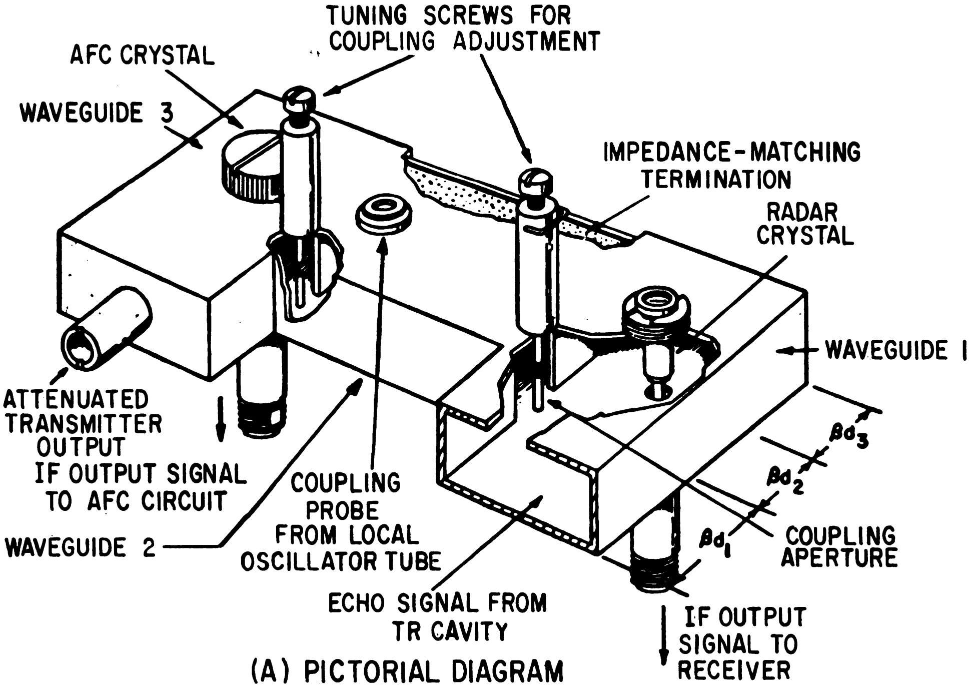
Local oscillator power and RF echo signals from the TR cavity are coupled into waveguide 1, which serves as the echo signal channel. A crystal extends between top and bottom walls of the guide, the lower end of the crystal being isolated from the guide by means of a dielectric washer. Echo signal voltages in the intermediate frequency band appear between the lower end of the crystal and the waveguide and are conducted to the input circuit of the IF amplifier, usually over a coaxial cable.

Waveguide 3 is similar in construction to waveguide 1 and serves as the AFC channel. Power from the local oscillator and a small amount of the transmitter pulsed power are applied to the AFC crystal, and IF signals for the AFC circuit are derived at the lower end of the crystal mount, as before. Attenuation between the transmitter main guide and guide 3 is provided by means of a circular waveguide section operating below cutoff. Sometimes a disk type of attenuator is included in the circular section to reduce further the amount of transmitter power reaching the mixer assembly.

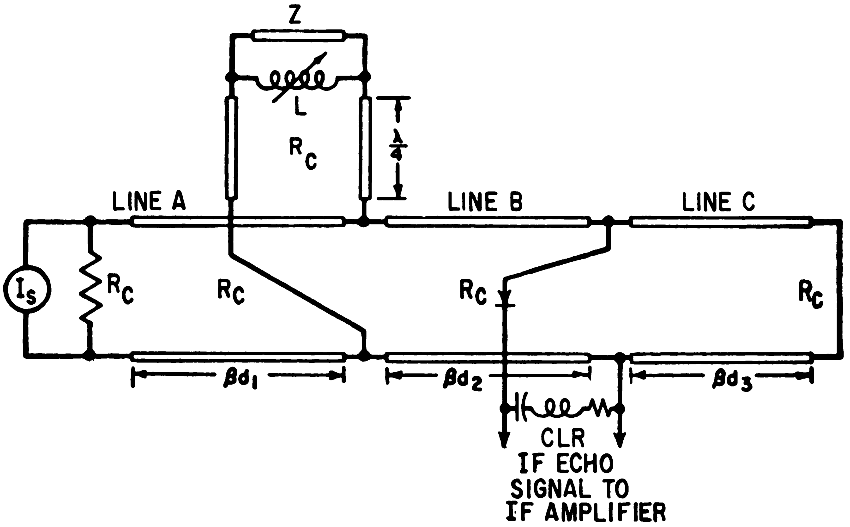
The local oscillator tube is mounted above waveguide 2 in a manner that permits the local oscillator output probe to extend a short distance into guide 2. The coupling probe may be displaced slightly from the center of the transverse axis of the guide in order to obtain a load impedance for the oscillator which yields a reasonably uniform power output over the tuning range.

Local oscillator power is coupled from guide 2 into guides 1 and 3 through coupling apertures located in the side walls of the guides. A matching post and tuning screw extending from top and bottom walls of the guides at the aperture locations serve to regulate the amount of local oscillator power coupled to the mixer circuits.

For optimum performance of the radar system, the echo signal channel of the mixer should


TUNING SCREWS FOR COUPLING ADJUSTMENT
AFC CRYSTAL
WAVEGUIDE 3
IMPEDANCE-MATCHING TERMINATION
RADAR CRYSTAL
WAVEGUIDE I
βd3
βd2
βd1
COUPLING APERTURE
ATTENUATED TRANSMITTER OUTPUT
IF OUTPUT SIGNAL TO AFC CIRCUIT
WAVEGUIDE 2
COUPLING PROBE FROM LOCAL OSCILLATOR TUBE
ECHO SIGNAL FROM TR CAVITY
IF OUTPUT SIGNAL TO RECEIVER

(A) PICTORIAL DIAGRAM



(B) AN RF EQUIVALENT CIRCUIT OF ECHO-SIGNAL CHANNEL

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Figure 9-7. –A 3-cm single-ended mixer.

provide a matched load impedance to the waveguide transmission system. The elements that determine the mixer input impedance are shown in the equivalent circuit of figure 9-7 (B). The equivalent circuit is derived by dividing guide 1 into three sections of lengths βd_1, βd_2, and βd_3 and representing the sections by equivalent lengths of transmission lines (lines A, B, and C in fig. 9-7 (B)). The signal current generator I_s in shunt with R_c in the equivalent circuit accounts for the portion of the RF system between antenna and mixer. The coupling aperture between local oscillator and mixer guides (guides 1 and 2) is represented by a variable inductance L, and in shunt with L is an impedance Z which accounts for the impedance seen in the direction of the local oscillator guide. The parallel combination of L and Z terminates a quarter-wave section of line which is in shunt with lines A and B. At the echo signal frequency, the impedance of L and Z in parallel is maintained small enough in comparison with the characteristic resistance of the quarter-wave line to make the input impedance of the quarter-wave section extremely high and hence the amount of echo signal power entering the local oscillator guide extremely small.

The crystal is located at the junction of lines B and C, as shown in figure 9-7 (B), and across the crystal output terminals is a series RLC circuit. The counterpart of the RLC combination in figure 9-7 (A) is an RF choke in the IF output lead of the mixer. The choke prevents RF signals from entering the input circuit of the IF amplifier.

The length of shorted-end line C must be such that the input admittance of line C, in shunt with the RF admittance of the crystal, provides essentially a matched load for line B. Varying the length of line C changes the susceptance component of the total admittance at the crystal location. A length of approximately $\lambda/4$ is usually preferable in order to minimize changes in admittance with frequency.

Balanced Crystal Mixers

The noise introduced into the input circuit of a microwave receiver by the local oscillator may be reduced appreciably through use of a balanced mixer. An input circuit of this type employs two crystal mixers connected so that the local oscillator voltages applied to each crystal are in phase and the echo signal voltages at each crystal are 180° apart in phase. As explained below, this method of circuit connection causes the IF components of local oscillator noise to cancel in the IF amplifier input circuit and the IF components of the signal to add. Because of their ability to suppress local oscillator noise and because of certain additional advantages to be discussed later, balanced mixers are often preferable to single-ended mixers. They are presently finding wide use in microwave radar systems.

The basic principles of a balanced mixer may be explained from the diagram of figure 9-8, which shows two crystals mounted a half wavelength apart (at the signal frequency) between conductors of a coaxial line section. Each crystal is located a quarter wave from the nearer end of the line, and the local oscillator signal is coupled to the line by means of a probe at a point midway between the crystals. The output terminals of the crystals are connected to an IF transformer, the primary winding of which is balanced to ground. The signal current generator I_s in shunt with resistance R_c accounts for signals entering the mixer from the TR device.

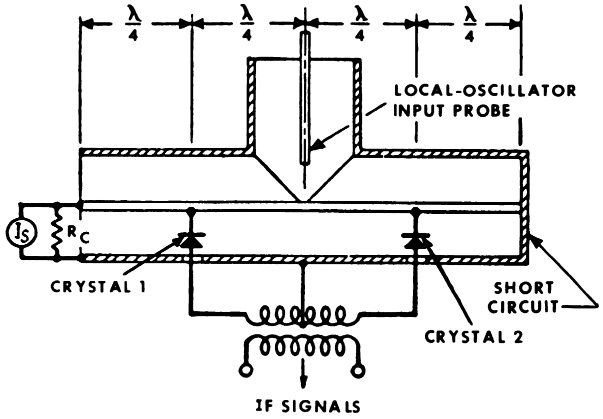

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Figure 9-8. –Balanced mixer circuit.

The local oscillator coupling probe gives rise to two waves traveling in opposite directions in the coaxial line. Assume that at the local oscillator frequency the TR device presents a short circuit to the local oscillator wave traveling to the left in figure 9-8 and that the crystals have identical RF impedance equal to twice the characteristic resistance of the line. Then inphase local oscillator voltages of equal amplitude appear at the crystals. Because of the 180° spacing between crystals, the RF echo signal voltages at the crystals are also of equal amplitude but are 180° apart in phase. An inphase relation between local oscillator and echo signal voltages produces an IF signal voltage of one phase and a 180° phase relation between local oscillator and echo signal voltages produces an IF signal voltage of opposite phase. Thus the two IF echo signal voltages add in the balanced input circuit of the IF amplifier. Because the noise that accompanies the local oscillator signal produces voltage components bear the same phase relation to the local oscillator voltage at each crystal, the corresponding

IF components of noise at the output of each crystal are in phase and hence produce no resultant noise voltage across the IF transformer.

In order to realize full benefit from use of a balanced mixer circuit, the crystals should have similar RF impedances as assumed above; and in addition they should have similar conversion gains. Under these conditions of operation, only one-half the available RF power is applied to each crystal; but since the IF signal powers from the crystals add together, the total IF power is the same as that obtained from a single-ended mixer. Since IF components of local oscillator noise are almost completely eliminated, maximum reduction in overall noise figure is obtained.

An imbalance in conversion gain yields an imbalance in the IF signal voltages obtained from each crystal and also an imbalance in the local oscillator noise voltages at the crystal output terminals. However, since the IF signal voltages are additive in the crystal output circuit and the local oscillator noise components are subtractive, small imbalances in conversion gains do not seriously affect the overall receiver noise figure.

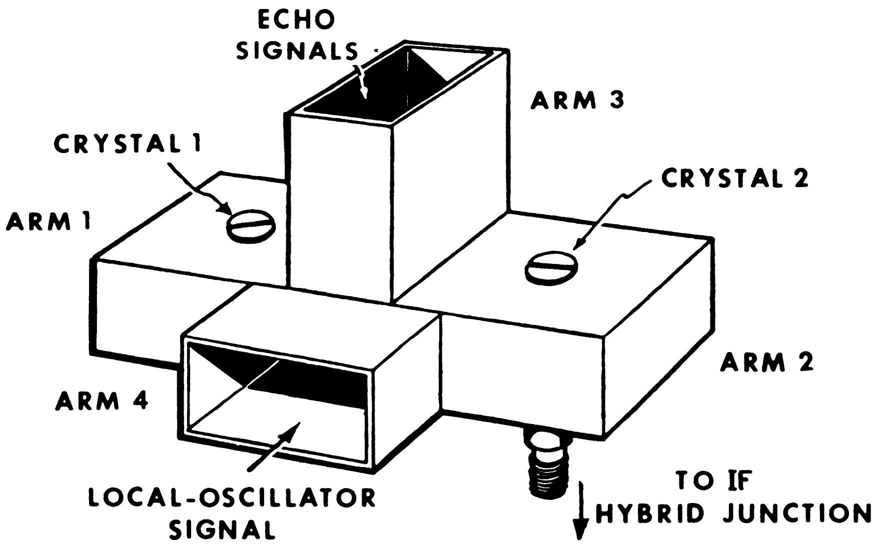
More important are the effects of a difference of the RF admittances of the crystals. An imbalance of this type causes both the echo signal power and the local oscillator power to divide unequally between the two crystals. As a result, the IF signal power obtained from the mixer is appreciably reduced, and in addition the local oscillator noise is prevented from canceling completely in the IF input circuit. Crystals intended for use in a mixer constructed as shown in figure 9-8 must be carefully selected on the basis of equal RF admittances in order to insure most satisfactory operation.

A balanced mixer that is superior in several respects to the coaxial line mixer just described is shown in figure 9-9 (A). This mixer employs a waveguide hybrid junction of the type discussed in chapter 6; this junction is often called a magic T. Crystals are located in one pair of entries (arms 3 and 4). Usually in a mixer of this type the input circuit of the IF amplifier is also arranged in the form of a hybrid junction. Details of connections of the IF amplifier input circuit, together with the ideal transformer equivalent circuit of the waveguide junction are given in the right-hand block of figure 9-9 (B). The parallel circuit comprising L, C, and R is tuned to the intermediate frequency and the impedance of the parallel combination of L', C', and R' is made equal to the conjugate of the IF impedance appearing between the terminals to which L', C', and R' are connected.

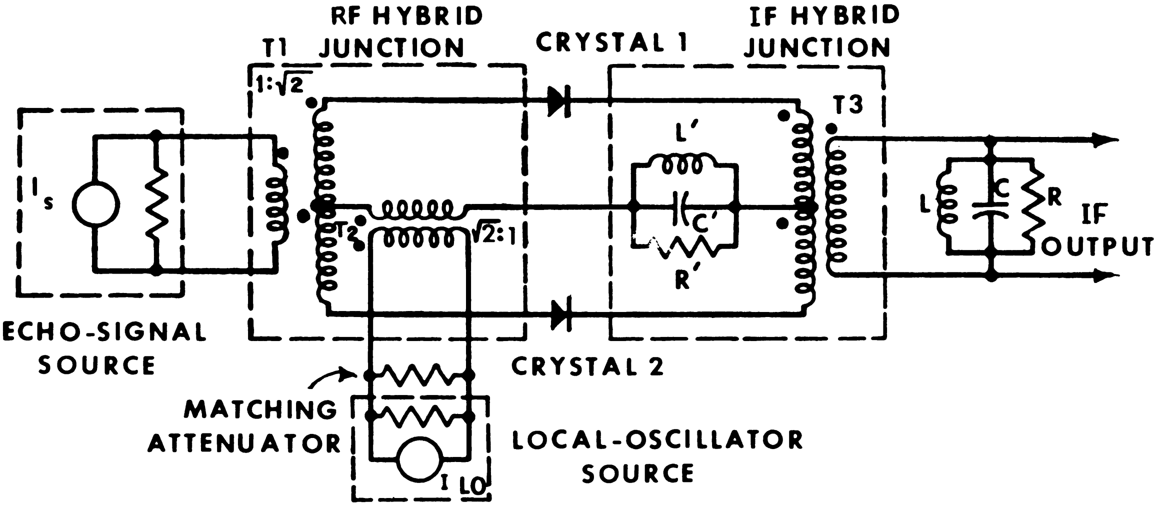
Ideally the two crystals should be alike. Furthermore, all RF impedances should terminate the entries of the RF hybrid junction in matched loads, and all IF impedances should similarly terminate the entries of the IF hybrid junction. Then, because of the properties of a matched hybrid junction, local oscillator signals at the crystals are equal in amplitude and in phase, and echo signals at the crystals are equal in amplitude and 180° apart in phase.

The IF components of signals from the crystals are applied in push-pull to ideal transformer T3 and appear across L, C, and R but not across L', C', and R'. The IF components of local oscillator noise, on the other hand, are in effect between end terminals of T3 in parallel and appear across L', C', and R' but not across the IF output terminals. Local oscillator noise is thus suppressed. Because the RF hybrid junction is matched, the total available power from the echo signal and local oscillator arms divides equally between the two crystals. As in the coaxial line mixer of figure 9-8, the IF power from each crystal is one-half the available echo signal power times the conversion gain G of the crystal. Since IF power from each crystal is delivered at the IF output terminal, the total IF output is the product of the echo signal and G, as before.

Ordinarily, in single-ended mixers and in the coaxial line balanced mixer (fig. 9-8), the local oscillator must be loosely coupled to the mixer in order to prevent an appreciable amount of echo signal power from entering the local oscillator circuit. As a result, the local oscillator must generate much more power than is actually needed for mixer operation, the excess power being dissipated in an impedance changing device located in the local oscillator circuit. Because in a hybrid junction mixer the echo signal and local oscillator arms are decoupled, there is no tendency for echo signals to enter the local oscillator circuit, and hence there is no need for loose coupling between local oscillator and mixer. A local oscillator with relatively low power output can therefore be used, the only power necessary being that which is needed to drive the crystals. Actually most local oscillators are capable of generating more than the minimum power required, so that a dissipative attenuator can be inserted in the local oscillator input waveguide section in order to insure a matched termination for the arm. Such an attenuator is desirable, as will be seen later.



(A) PICTORIAL DIAGRAM



(B) EQUIVALENT CIRCUIT

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Figure 9-9. –Balanced mixer employing hybrid junctions.

Decoupling between echo signal and local oscillator arms also means that there is no tendency for local oscillator power to enter the echo signal arm. Rejection of local oscillator signal by the echo signal arm is particularly advantageous in systems employing a broadband TR device which would allow local oscillator power to pass through and be radiated by the antenna.

Another advantage of the hybrid junction mixer is that its operation is less sensitive to differences in the RF impedance of the crystals than is the balanced coaxial line mixer. Because the two crystal arms are decoupled, any RF power reflected from one crystal cannot reach the other crystal. All the reflected power is directed into the echo signal and local oscillator arms and absorbed by the matched terminations. Thus the amount of RF power delivered to one crystal is independent of the RF impedance of the other.

If a mismatch should exist in either the echo signal or local oscillator arm, a reflection of an RF signal arriving at the mismatched termination will occur, and the signal reflected from the termination will enter the two crystal arms. Under these circumstances, the two crystal arms are not completely decoupled. At the echo signal frequency, a mismatch in the echo signal and local oscillator arms is unlikely because in general the TR device provides a matched load for the echo signal arm and, as indicated above, a matching attenuator can normally be inserted in the local oscillator arm.

In general, if the crystals provide an impedance match at the echo signal frequency, they do not yield a perfect match at the local oscillator frequency. This mismatch is unimportant, since the reflected power will be absorbed in the echo signal and local oscillator arms. The attenuator in the latter arm serves to prevent the returned signal from reacting on the oscillator. Should the echo signal arm not provide a matched termination for the returned local oscillator signal, further reflection of the signal will occur and the balance of local oscillator power at the crystals will be further upset. The effect of such an imbalance is to change the conversion gains of the crystals slightly, but usually the change is negligible even with moderate amounts of mismatch at the local oscillator frequency.

Use of the hybrid junction type of IF input circuit shown in figure 9-9 (B) insures suppression of local oscillator noise despite imbalance in the IF impedances of the crystals. When all entries of the IF hybrid junction are terminated in a load that is the conjugate of the impedance faced by the load, the two crystals, constituting one pair of entries, are decoupled and the two resonant circuits, constituting the other pair, are also decoupled. If the resonant load entries remain matched, the amount of IF signal power coupled from one crystal to the output terminals is independent even if the IF impedance of the other crystal does not match the arms. Furthermore, the IF components of noise cancel in the output circuit independently of the IF crystal impedance as long as the crystals develop equal IF noise voltage. The IF components of noise appear only across the L', C', and R' arm. If crystals are tested for equal conversion gains while loaded by the conjugate of the IF impedance of a typical crystal, equal IF noise voltages can be expected when the crystals are employed in the circuit of figure 9-9.

Terminating the IF output entry in a matched load does not in general insure minimum noise figure. Mismatching the output entry in order to minimize the noise figure alters the load for the push-pull IF echo signals and thus reduces the echo signal power delivered to the load but does not alter the load for the IF components of noise which are applied to T3 in parallel. The local oscillator noise suppression property of the mixer is therefore retained.

AMPLIFYING CIRCUITS

The receiver, in addition to converting the returned echo signal to a frequency capable of being amplified by vacuum tube amplifiers, must provide several stages of amplification plus other special circuits. The special circuits to be discussed are the automatic gain control and the automatic back bias circuits.

IF AMPLIFIER

A typical IF amplifier is shown in figure 9-10. The output of the crystal mixer is fed through a coaxial cable to the IF amplifier. The mixer's output contains all the frequencies present in the mixing chamber since the crystal is not frequency selective. However, the amplifier's input circuit contains an input impedance network that is tuned to the intermediate frequency. The impedance network, which is composed of L1, L2, and L3, is also used to match the input impedance of the amplifier to that of the coaxial cable. It should be noted that L2 is tunable and determines the degree of coupling between the mixer and the first amplifier. The microwave signal and local oscillator signal are developed across the crystal current section of an impedance network which consists of C2, C3, C4, L4, L5, and the receiver crystal current meter. The capacitors and inductors provide the necessary filtering action to smooth out the rectified RF.

The crystal current meter, normally a milliammeter located on or near the control box, serves two main functions. It is used to monitor the power output of the klystron local oscillator during receiver alinement, and it serves to give a visual indication of the receiver crystal's condition, thus indirectly monitoring the receiver's sensitivity during operation. In some aviation fire control radar sets, the same meter is also used to indicate magnetron current, various regulated a-c and d-c voltages used by the

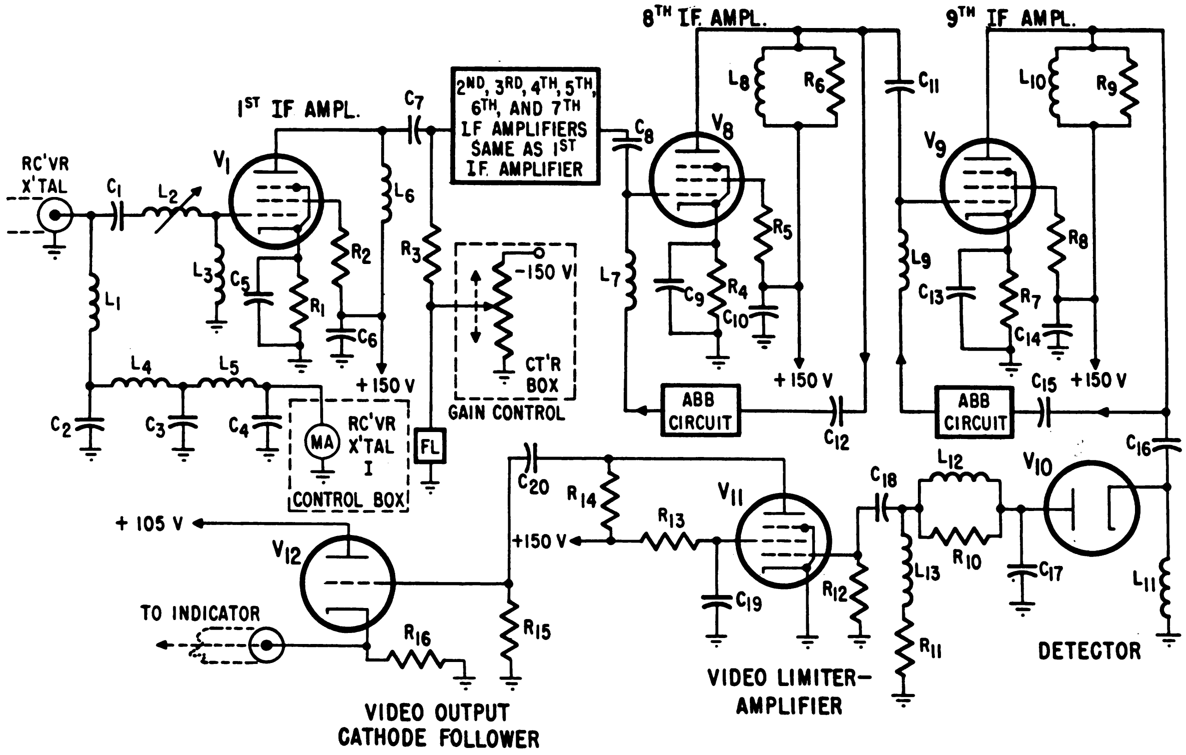

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Figure 9-10. -IF amplifier, detector, and videocircuits.

radar set, and beacon crystal current. This is accomplished by means of a selector switch that the operator may use to select the circuit to be monitored.

The first stage of the IF amplifier is the most critical of the entire amplifier since it is in this stage that the signal to noise ratio is mainly determined. Cathode bias, which is developed by R1 and C5, is employed. The plate load which consists of L6, the distributed capacitance of the plate leads and of L6, and the interelectrode capacitance of the tube, is resonant to the intermediate frequency.

IF amplifiers 2 through 7, shown in block form, are similar to the first IF amplifier with the exception of the grid returns. Their bias, and thus the gain of the IF amplifier, is determined by the setting of the potentiometer gain control. Also in most aviation fire control radar equipments, one or more stages of the amplifier are provided with a means of changing the bandwidth. During long pulse operation, the bandwidth is normally reduced to eliminate much of the clutter and noise. This is usually accomplished by removing a swamping resistor placed in parallel with the resonant tank in the plate of one or more of the amplifier stages (usually the 4th and 5th or the 5th and 6th). Narrowing of the bandwidth normally increases the gain of a stage. Thus, when this is done, a cathode resistor is switched into the affected stage or stages to eliminate the undesirable change in gain.

The 8th and 9th IF amplifiers are also conventional amplifiers with the exception of the automatic back bias (ABB) circuit contained in each stage. The purpose of the ABB circuit, sometimes called instantaneous automatic gain control, is to provide instantaneous gain control of the two stages, thus preventing or reducing the possibility of the receiver being saturated by strong return signals.

A typical ABB circuit is illustrated in figure 9-11. The output signal from the plate of the IF amplifier stage is coupled to the ABB circuit as well as to the next stage. The signal is coupled through C1 to the cathode of the diode V1. When a signal is present, an a-c voltage is developed across L1 and the diode operates and rectifies the IF pulses. The rectified current

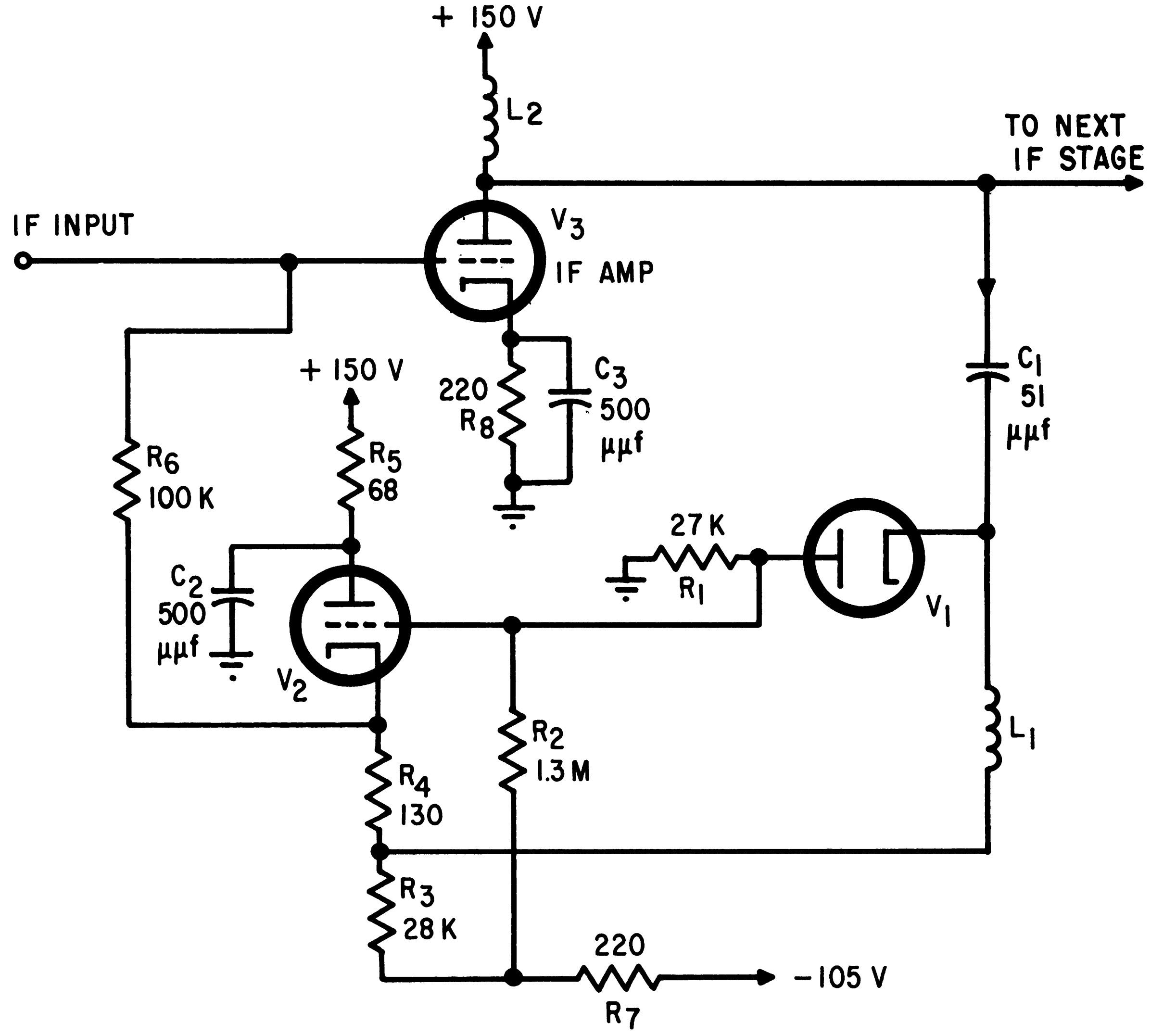

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Figure 9-11. –Automatic back bias circuit.

develops a negative voltage across R1 which is direct and coupled to the grid of V2 driving it negative and reducing V2's plate current. Consequently, the voltage drop decreases across R3 and R4. The voltage drop across R3 is also felt by the cathode of V1 as a further decrease in cathode voltage. This feedback action quickens and amplifies the bias expansion.

Since the grid bias of the IF amplifier is determined by the algebraic sum of the voltage across the cathode resistors and the minus 105-volt supply, the grid bias increases and reduces the IF amplifier's gain. The reduction in the IF signal occurs almost instantly. Thus, each received signal block is sharply cutoff and effectively narrowed by the ABB circuit. This reduces signal smearing, particularly on sea clutter, jamming, and large land masses.

DETECTOR AND VIDEO AMPLIFIER

The output of the IF amplifier is coupled through C16 to the cathode of the diode detector V10. (See fig. 9-10.) The output of the detector, the rectified IF signal, appears across the tuned circuit (L12-R10), L 13, and

R11. The IF component of the output signal is filtered out by the capacitor C17, leaving only the video envelope to be fed to the video amplifier and limiter.

The video section consists of a video amplifier and limiter, V11, and a cathode follower, V12. With no applied signal, the video amplifier is biased essentially at zero. Since the output of the detector is negative, a negative signal reaches the amplifier grid. Although the signal is negative, it is capacitively coupled and attempts to average itself about the bias level of the amplifier. However, any positive swing causes grid current to flow, charging C18, which develops an opposing bias across the grid resistor. Consequently, zero signal bias level is held constant and the applied signal only swings the grid negative (negative clamping). The extent to which the grid is driven negative is set by the cutoff bias, which is relatively low due to the selected screen voltage. Therefore, the signal is effectively confined within the zero bias and cutoff voltage levels.

The output from the video amplifier is coupled through capacitor C20 to the cathode follower, V12, which transforms the high impedance to a low impedance to match the coaxial line supplying video to the indicator. NOTE: Cathode followers and video amplifiers are discussed in detail in Basic Electronics.

AUTOMATIC GAIN CONTROL

The amplitude of the received signal from a particular target may vary because of fading and rapid changing of its position relative to the radar antenna. If the receiver has constant gain, there is a corresponding variation in the amplitude of its output. If this changing amplitude is objectionable, as in systems where the signal is used for automatic tracking, an automatic gain control circuit may be used. The gain control circuit automatically gives greater gain when the received signal is weak than when the received signal is strong. Thus, the amplitude of the receiver's output is maintained relatively constant.

A common type of automatic gain control circuit uses the IF signal voltage to control the bias on one or more of the IF amplifier stages. A d-c voltage obtained from the output of the detector is used for this purpose. If the signal is too strong, the grid of the IF amplifier stage is made more negative to reduce the gain. A remote cutoff tube is usually used in this type of gain control circuit to prevent excessive distortion of the received signal.

NOTE: Another method of controlling the gain of an amplifier is by controlling the voltage on the screen grid. Thus, by the use of a series of d-c amplifiers, the d-c output from the detector can be used to automatically control the gain of the IF amplifiers.

An automatic gain control circuit used in aviation fire control radar must be capable of controlling the gain based on the strength of a particular target. That is, the receiver gain must be automatically controlled to give a constant receiver output from the selected target regardless of the strength of the received signals from the other targets. This is accomplished by blanking the AGC circuit at all times except when the echo from the selected target is being received. A special circuit, commonly called a tracking circuit, generates the pulse that is supplied to the AGC circuit for unblanking.

AUTOMATIC FREQUENCY CONTROL

Automatic frequency control (AFC) systems are classified in accordance with their method of operation. The method of operation may be divided into two major classifications, the absolute and the difference frequency systems.

In the absolute frequency system the frequency of oscillation is determined by a precision frequency standard such as a high-Q cavity. This system is generally used to keep the receiver tuned to the beacon (RACON) frequency. In the difference frequency system the local oscillator is maintained on a frequency which is greater or less than the magnetron frequency by an amount equal to the intermediate frequency.

Either of these systems may be of the nonhunting or hunting type construction. The hunting system is constructed to cause the oscillator to sweep a wide frequency range. This enables the oscillator to find the correct operating frequency, and once this has been accomplished the oscillator will automatically remain on the correct frequency. This system has the advantage that in the event of a sudden shift in magnetron or local oscillator frequency the correct operating frequency will be found automatically. In the nonhunting system the oscillator is manually tuned to the correct frequency and then maintained electronically to this frequency.

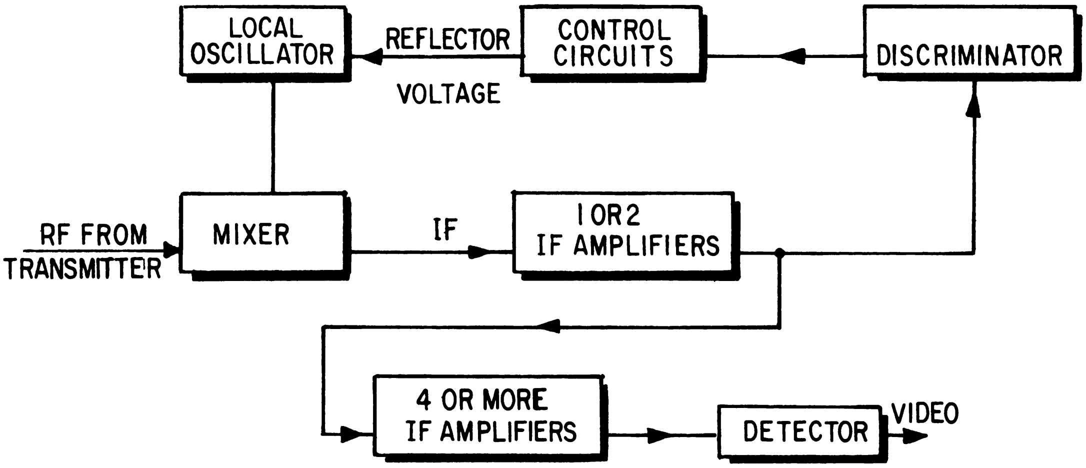

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Figure 9-12. –Block diagram of AFC circuit in a radar receiver, single-mixer system.

SINGLE-MIXER SYSTEM

In the single-mixer system (fig. 9-12), a portion of the transmitter pulse leaks through the TR box and beats with the local oscillator signal in the mixer. The difference frequency, or the IF signal, appears at the output of the mixer. This IF signal is then amplified by one or two stages of IF amplification. At this point the signal follows two paths–it is further amplified and fed into the detector, and it is also fed into the AFC discriminator. The output of the discriminator is fed to either a d-c amplifier or some special control circuits which regulate the klystron repeller plate voltage. The regulation of this voltage changes the frequency of the klystron and enables the local oscillator to oscillate at the correct frequency.

DOUBLE-MIXER SYSTEM

Most modern radar systems use a double-mixer AFC system, as shown in figure 9-13. The separate signal and the AFC mixer are both connected to the same local oscillator. This arrangement is shown in figure 9-13. The AFC mixer is coupled to the transmission line through an attenuator which reduces the transmitted pulse and received signals by the same ratio. With this arrangement, strong signals from nearby radar, jammers, or sea return cannot affect the operation of the AFC loop. The double-mixer system is similar in action to the single-mixer system but uses special magnetron frequency input and contains an AFC attenuator and separate IF stages.

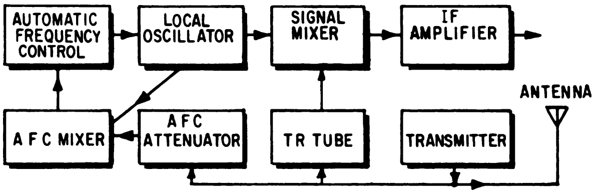

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Figure 9-13. –Block diagram of a double-mixer AFC system.

Discriminator Circuit

The amplified output of the AFC mixer is fed into the AFC discriminator. The output voltage of a frequency discriminator varies in amplitude and polarity with changes in the applied frequency. If the applied frequency is at the resonant or center frequency of the discriminator, the output will be zero. If the applied frequency is above or below the correct value, the output of the discriminator will be either positive or negative, depending upon the direction of diviation.

Thyratron AFC Control Circuit

The Thyratron AFC control circuit is an automatic hunting and lock-in type. A simplified

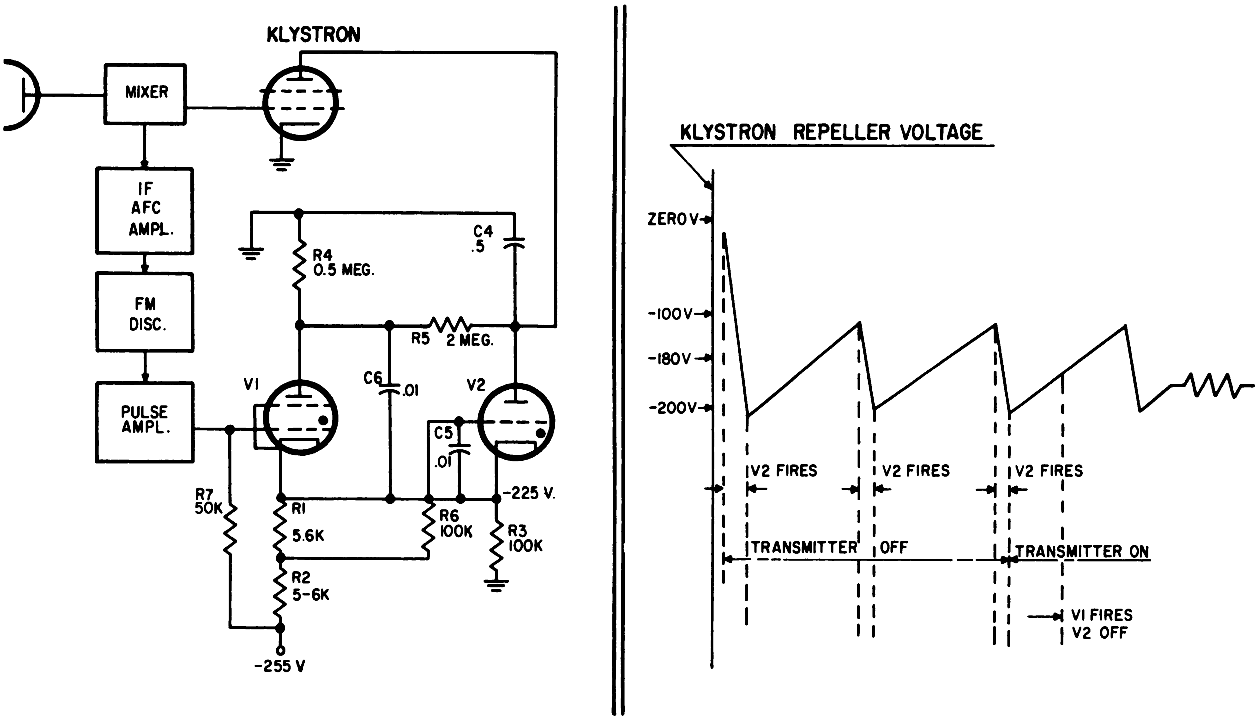

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Figure 9-14. -Thyratron AFC control circuit.

diagram is shown in figure 9-14. Since the discriminator time constant is short, a pulsed output is produced. These pulses are amplified and inverted by the video pulse amplifier.

In the circuit shown in figure 9-14, V2 functions as a sawtooth sweep generator. The output of this generator is applied to the repeller of the klystron. This causes a wide frequency band to be swept by the klystron and provides a "hunting action," which is a requirement of the AFC system. Lock-in action is obtained by V1 once the proper IF signal is produced. During the time that V1 maintains lock-in, V2 will remain cut off because the action of V1 prevents the plate potential of V2 from rising to the point of tube ionization.

In the explanation of this circuit it is assumed that the radar transmitter is turned off. There will be minus 30 volts bias applied to V1 because of the 30-volt drop across R1 and R2. This IR drop is a function of the divider network R1, R2, and R3. V1 will remain cut off because there will be no signal input to the grid until the transmitter is turned on. Since C5 cannot be charged instantaneously, the moment that power is applied V2 will have zero volts bias and a plate to cathode potential of plus 225 volts. As a result of these potentials, the gas in V2 will ionize and the tube will conduct. During the time that V2 conducts, C4 will charge towards a minus 225 volts through the low internal resistance of V2. During this charging period the plate to cathode voltage of V2 will decrease.

The de-ionization potential of a gas tube is a function of the type of gas, the pressure, and the fixed geometrical characteristics of the tube. This dependence on tube characteristics which are less uniform for thyratrons than for vacuum tubes, is one disadvantage of the gas-tube control circuit. For instance, for a fixed bias of the magnitude used in the sweep generator circuit of figure 9-14, V2 may start conduction at any plate voltage within a 100-volt range and still be acceptable under MIL specifications. Without correction this might result in a 50-percent change in the sweep range when V2 is replaced. There are two methods of correction. In some instances correction is provided by a resistive network between the grid and the plate which introduces negative feedback to minimize the spread in firing potential. A second method is in the form of a bias adjustment in the grid circuit which may be reset, when V2 is changed, to bring the firing potential to the desired level.

The tube used in this circuit, V2, will deionize at 25 volts. Thus, when the charge on C4 has reached 200 volts, V2 will de-ionize. When this occurs, C4 discharges through R4 and R5 to ground and the plate of V2 becomes less negative. The discharge continues until the charge on C4 is about 100 volts. At this point, the plate to cathode potential is sufficient to again ionize the tube. (The ionization potential of a gas tube is a function of its grid bias.) The sawtooth output of V2 is applied to the klystron repeller and since this output voltage varies between a minus 100 and a minus 200 volts, the amplitude of the sawtooth waveform is 100 volts. The recurrence frequency of this sawtooth is approximately 1 hertz.

To aid in understanding how the AFC loop is completed, assume that the klystron will oscillate at the proper frequency when its repeller voltage is between minus 170 and minus 140 volts. As a result of V2's sawtooth output, the oscillator will be electrically tuned through the proper frequency during each sawtooth period. When the transmitter is turned on, assume that the proper intermediate frequency will be obtained with a repeller voltage of minus 155. When the repeller is more negative than minus 155 volts, the input to the grid of V1 will be negative. Thus, V1 will remain cut off. The discharge of C4 causes the repeller voltage to become less negative.

As this voltage becomes less negative than minus 155 volts, the input to the grid of V1 will be positive pulses. At some frequency the pulses will be of sufficient amplitude to ionize V1, thus providing a new longer RC charging path for C4. This path extends from the minus 225 volts on the thyratron cathodes through V1 and R5 to C4. As C4 again charges, the repeller voltage will again become more negative; when this voltage passes through the minus 155-volt point, the input to V1 will again become negative pulses. Thus V1 will de-ionize as soon as C6 discharges through it. R5 drops sufficient voltage to keep ionization from being maintained, although C4 has not reached the 200-volt level. The de-ionization occurs when C6 has discharged to the de-ionization potential of V1 which is about 25 volts. After V1 has deionized, C4 will again discharge through R4 and R5 to ground.

Having been discharged, C6 will regain its charge quickly, primarily through R4. This causes C4 to charge while the charge current of C6 produces a negative voltage at the bottom of R4, bringing the repeller back more negative than minus 155 volts. After C6's rate of charge has waned, the bottom of R4 approaches ground, and C4 resumes its interrupted discharge again. After passing minus 155 volts, a positive pulse ionizes V1, and the cycle repeats.

This entire cycle will be repeated at a rate of about 200 Hz. (NOTE: Only the positive pulses on the grid of V1 have any effect.)

The amplitude variation of the repeller voltage is so slight that the variation in klystron frequency is only a small fraction of the receiver's IF bandwidth. Because of this action the receiver will remain tuned, or locked-in, to the transmitting frequency. When the circuit is locked-in, V1 will be conducting periodically and V2 will remain cut off. Thus, V2 is effectively disconnected from the circuit. The only purpose of V2 is to provide a slow, continuous sweep to hunt for the proper operating point and to reestablish circuit operation. This action will occur whenever AFC operation is interrupted.

AIRBORNE MOVING TARGET INDICATION

Sea clutter has always hampered radar operation over water and seriously degraded the effectiveness of high altitude search radars. In fact, the effectiveness of present aircraft operation is often dependent on the sea clutter problem. As an example of this problem, an aircraft flying at 10,000 feet would have a radar range to the horizon of 120 miles; but in rough sea conditions, sea clutter might extend to ranges of almost 100 miles. Flying at higher altitudes causes the clutter intensity to increase and causes its range to increase.

Since high sea state (waves 8 feet and above) conditions exist over 50 percent of the time during winter months over the North Atlantic and sea states sufficient to cause considerable clutter are present 80 percent of the time during the same period, the problem of sea clutter becomes a serious one.

Airborne moving target indication (AMTI) becomes desirable from two standpoints: First, it allows only moving airborne targets to be presented on the scope; and second, it reduces the sea clutter return on the scope. The requirement for a satisfactory AMTI is one of long standing, and one that is even more pressing now with the advent of automatic radar data processing devices.

PRINCIPLES OF AMTI

The function of the AMTI system is to cancel or attenuate signals received from fixed targets, while permitting signals from moving targets to be amplified and sent to the indicating system. The AMTI system does this by comparing the phase of each returning target echo from the preceding transmitted pulse. In the comparison process, signals with like phase (from fixed targets) are canceled, and signals with unlike phase (from moving targets) leave an uncanceled residue.

Phase Detection

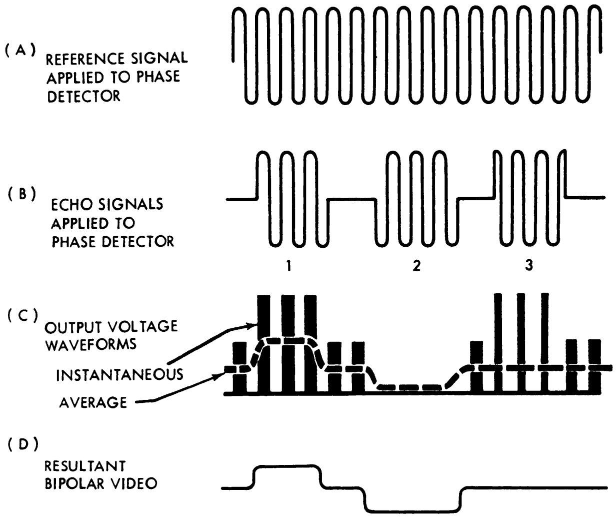
Due to the Doppler effect, the frequency of a signal reflected from a moving target is different from the transmitted frequency. In a radar system, the actual frequency changes are minor due to the fact that aircraft velocities are very small compared to signal velocity. This makes it impracticable to make a direct frequency comparison between the transmitted and received signals. Instead, a method of phase comparison is used to determine the pulse-to-pulse phase shift of returning signals.

Figure 9-15 illustrates the phase detection principle involved.

In this diagram, if you assume that the reference signal (A) is held constant with the starting phase of each transmitted pulse, it becomes apparent that echo signal (B) will give the same resultant video (D) for successive pulses from the same stationary targets. If, however, one of the echoes in (B) is a reflection from a moving target, a phase shift will take place between successive pulses (because of the Doppler effect), and the resultant video (D) will have greater or less amplitude. This phase detection principle is valid for an AMTI system only under the condition that the reference signal (A) assumes the same starting phase as each successive transmitter pulse.

TYPES OF MOVING TARGET INDICATION

There are two basic types of moving target indication systems–coherent and noncoherent. The coherent system depends upon an internally generated signal from a coherent oscillator. The noncoherent system depends upon ground clutter to supply its reference.


(A) REFERENCE SIGNAL APPLIED TO PHASE DETECTOR
(B) ECHO SIGNALS APPLIED TO PHASE DETECTOR
1
2
3
(C) OUTPUT VOLTAGE WAVEFORMS
INSTANTANEOUS
AVERAGE
(D) RESULTANT BIPOLAR VIDEO

SIGNAL 1. IN PHASE WITH REFERENCE SIGNAL
SIGNAL 2. 180° PHASE SHIFT FROM REFERENCE SIGNAL
SIGNAL 3. 90° PHASE SHIFT FROM REFERENCE SIGNAL

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Figure 9-15. –Phase detection of returning echo signals.

Coherent System

In a true coherent system, a signal from a coherent oscillator is locked in with the transmitted pulse to provide a reference signal, and a phase shifter is employed to compensate for the effect of the airborne radar's motion. This phase shifter must be servoed to the aircraft's velocity and the antenna azimuth.

Noncoherent System

In the noncoherent type of moving target indication, the return from either ground clutter or a fixed target is used as a reference signal. These signals will appear to remain constant in amplitude, from one transmitted pulse to the next, where the moving target is constantly changing in amplitude.

THEORY OF OPERATION OF A TYPICAL SYSTEM

The AMTI feature of the search radar is designed to display moving surface targets while suppressing the display of fixed targets and ground return.

The AMTI, as used in the A-6 type aircraft, is a noncoherent type which requires that the target must have motion with respect to ground clutter or permanent echoes with the same range in order to be processed as video on the Bombardier/Navigator's (B/N's) Direct View Indicator (DVI) and the Pilots' Horizontal Display System (PHD).

The search antenna radiates RF energy in the form of a pulse which illuminates an area that is determined by the antenna beamwidth in azimuth (1.4°) and the pulse width in range (0.4 microseconds or 200 feet).

The RF energy reflected from the scanned area is composed of a large number or randomly phased components representing ground clutter, permanent echoes, fixed targets, and moving targets.

It is characteristic of moving surface targets to give returns which fluctuate in amplitude above the normal ground return video. Moving target video will change amplitude from one pulse to the next while fixed target and ground return video will appear to have maintained a constant amplitude in the time between pulses. The moving target video changes amplitude (or modulates) because the phase of the radiofrequency return from the moving target is constantly changing with respect to the RF return from the surrounding ground area. The return from a fixed target is of greater amplitude than the return from the surrounding ground area. Because the fixed target does not move relative to the ground, the amplitude of its radar return remains constant from one pulse to the next. The search AMTI detects the fluctuations of moving target returns and amplifies and displays them while suppressing or canceling the constant amplitude returns of fixed targets and ground.

In AMTI operation, the returning search radar video is converted from an amplitude modulated signal to a frequency modulated signal, fed through both a delayed and a direct channel, and compared with the delayed signal from the previous pulse. By the manner in which the delayed and direct signals are compared, the frequency-stabilized fixed target and ground returns are canceled, and the changing frequency representative of moving targets is amplified. Since the delayed pulse must be delayed by a very exact amount, a specially stabilized 2,400 pulse per second trigger is generated for AMTI use. This is the search primary trigger. The search secondary trigger, available for the B/N's use, is not sufficiently stable to be used for AMTI operation.

The AMTI control on the B/N's control box. (fig. 9-16) controls the video mixer and allows the B/N to select full moving target video, regular search radar video, or any mixture of the two. The design of the AMTI circuits is such that the return from a moving target is enhanced by being compared with, or referenced to, the ground or fixed target return. Therefore, in the absense of ground or fixed target returns, moving targets are treated as fixed targets and are suppressed or completely canceled. It could be expected that a heavier ground return would optimize the moving target indications; however, rock outcrops and hard targets are usually not fully canceled and tend to distract or confuse the B/N. If doubt exists as to whether a return is displayed as a moving target return or a fixed target return, the audio circuitry of the track radar can be helpful in determining whether the target is moving or fixed, and in the case of a moving target, the relative size and/or speed may be determined by the pitch (frequency) of the audio.

The amplitude fluctuations caused by a moving target are only detectable for the range component of target movement. For this reason, a target that is moving on a line perpendicular to the aircraft heading will not be detected. The detection range of a given moving target will increase as the aircraft approach heading approximates the fore-and-aft axis of the target movement (head-on or tail-on approach). The relative approach angle (angle-off) between aircraft and target becomes most critical with slow moving targets. For example, a 10-mile per hour pickup truck and a 4-mile per hour road grader, traveling the same road, could both be detected at the same range on a 0° angle-off run, but the detection range for the road grader would be half that of the truck on a 10-mile angle-off run.

Since the AMTI operates on the principle that a moving target causes amplitude fluctuations above the normal ground return, the AMTI circuits are extremely noise and jitter sensitive. Radar receiver noise or magnetron jitter can render the AMTI virtually useless. Experience has shown that a radar which the B/N believes to be excellent in all other respects can, in fact, be practically useless for AMTI operation due to the noise. The only check the B/N can make is to check automatic frequency control (AFC) operation against manual frequency control (MAN) for maximum radar range or best land/water contrast. If MAN is significantly better

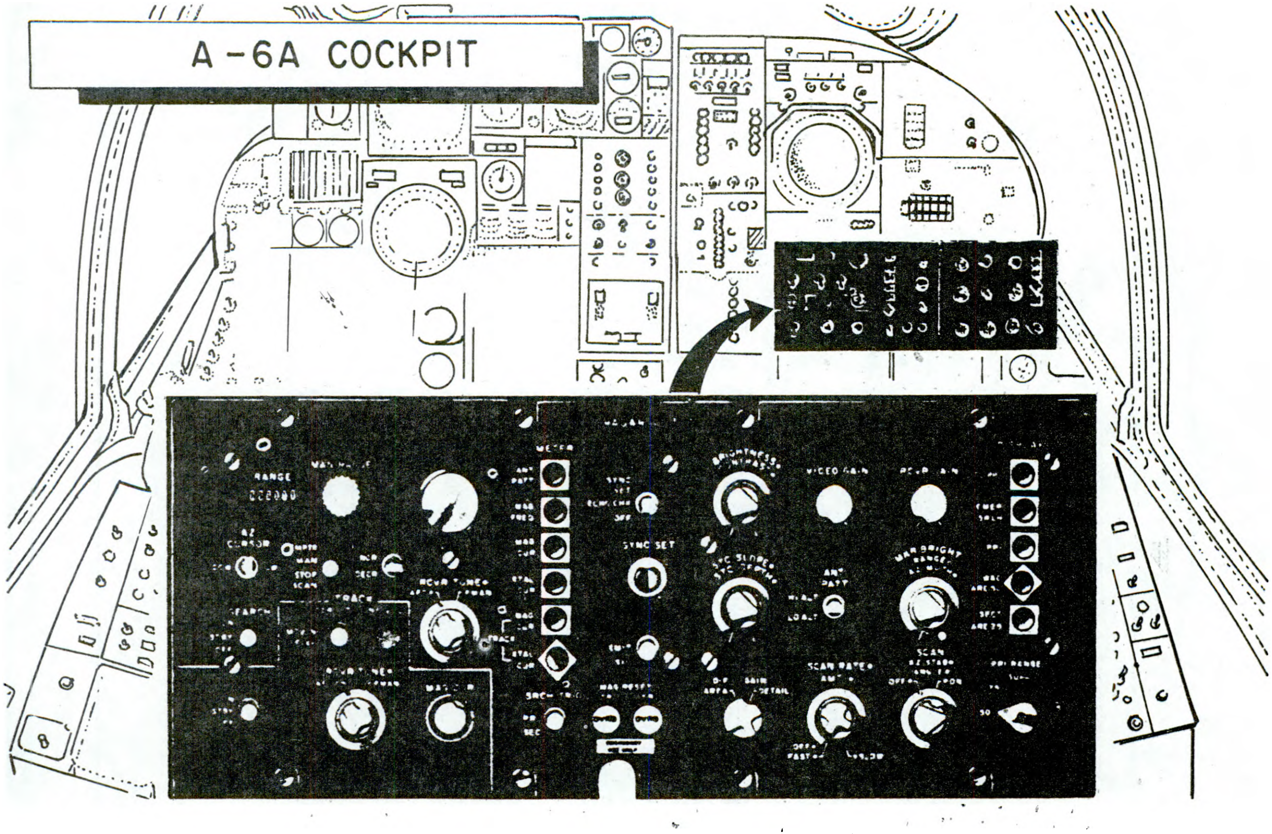

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Figure 9-16. –Bombardier/Navigator's control panel.

than AFC, it should be used. The real difference in above average AMTI lies with the quality of the radar maintenance. For first-class AMTI, the maintenance crews must periodically look at the radar magnetron for jitter, and closely monitor the radar receiver for clean noise-free video. Additionally, the technicians should be alert to any indication of progressive radar degradation provided by B/N debriefing.

SEARCH RADAR TERRAIN CLEARANCE (SRTC) MODE

The search radar terrain clearance display provided on the vertical display indicator (VDI) affords a means of maintaining terrain clearance along the projected flightpath of the aircraft. A 53° by 26° window of the terrain about the aircraft ADL is displayed on the VDI (fig. 9-17) with the attack and navigation steering functions.

The display consists of a perspective plot of range and elevation angle vertically, and azimuth horizontally shown on the VDI. Terrain clearance information is sensed by a dual channel horn mounted on the search radar antenna receiver. This array receives ground returns from search radar transmissions (pulse-for-pulse with the search radar.)

The search radar antenna receiver derives range information from search radar timing, azimuth information from antenna position, and terrain elevation information from phase variations.

The display presentation provides 10 shaded increments starting with the lightest shade in the near ranges at the base of the display, and progressing to darker gray tones toward the horizon, or far ranges. These shades of gray each represent a specific range increment ahead of the aircraft. All symbols and markers are available on this display except for the ground and cloud texture elements and the pitch trim markers. These are removed to avoid unnecessary scope clutter. Phase video and

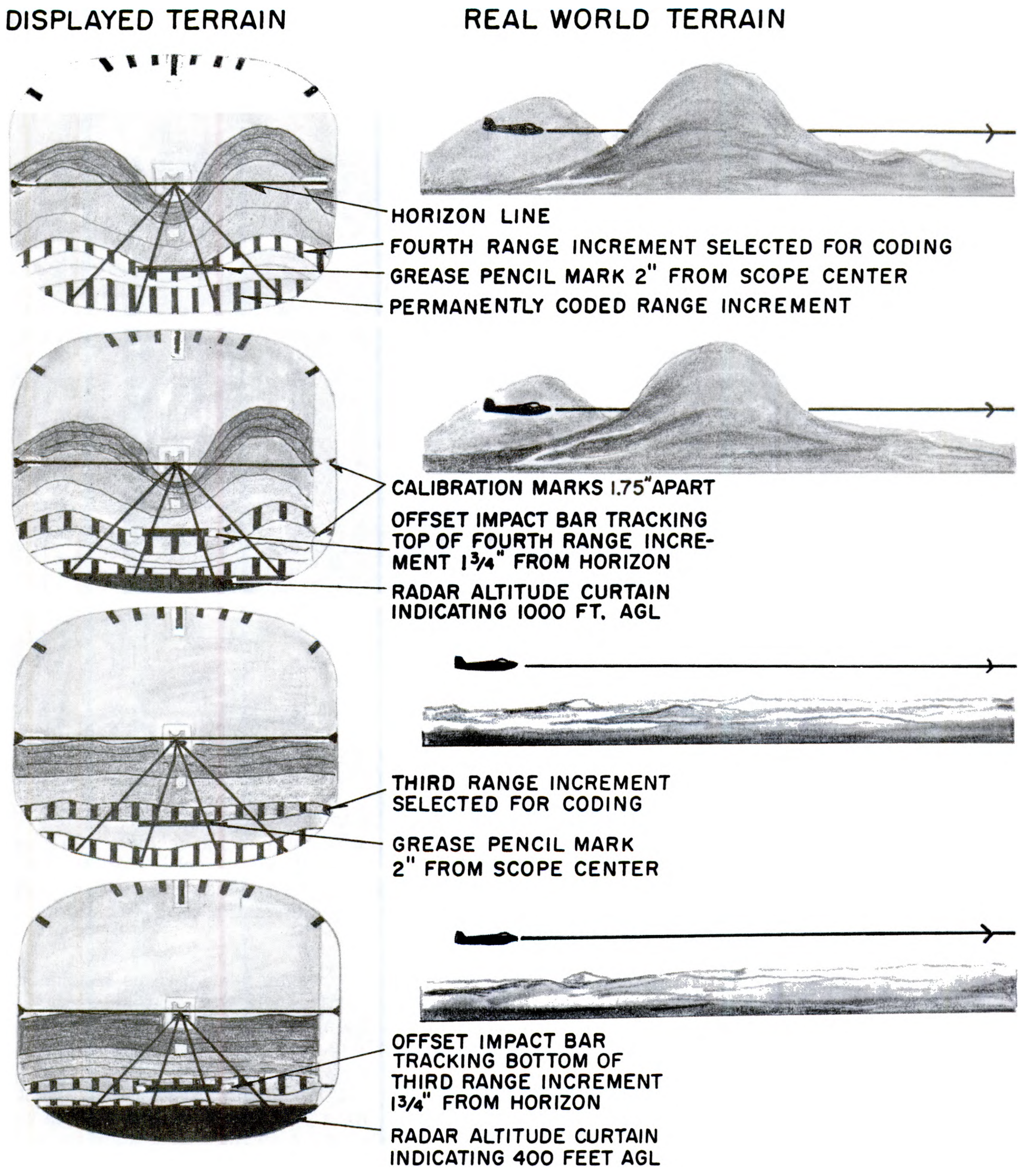
DISPLAYED TERRAIN
REAL WORLD TERRAIN
HORIZON LINE
FOURTH RANGE INCREMENT SELECTED FOR CODING
GREASE PENCIL MARK 2" FROM SCOPE CENTER
PERMANENTLY CODED RANGE INCREMENT
CALIBRATION MARKS 1.75" APART
OFFSET IMPACT BAR TRACKING TOP OF FOURTH RANGE INCREMENT 1 3/4" FROM HORIZON
RADAR ALTITUDE CURTAIN INDICATING 1000 FT. AGL
THIRD RANGE INCREMENT SELECTED FOR CODING
GREASE PENCIL MARK 2" FROM SCOPE CENTER
OFFSET IMPACT BAR TRACKING BOTTOM OF THIRD RANGE INCREMENT 1 3/4" FROM HORIZON
RADAR ALTITUDE CURTAIN INDICATING 400 FEET AGL

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Figure 9-17. –Search radar terrain clearance display.

terrain clearance amplitude video are processed through the terrain clearance processor. The radar data converter accepts the processed video and converts the signals to a television format acceptable to the VDI.

In the later model A-6 aircraft, the SRTC mode has been modified to improve its reliability. A radar altitude curtain has been added to the display. This curtain presents an analog of aircraft altitude (AGL) and is positioned by signals from the radar altimeter. Radar altitude signals are sent directly to the radar data converter and no longer go through the air data computer. Calibration marks have been added to the display as an aid in determining the credibility of the display. In addition, a movable offset impact bar has been added to enable the pilot to select the clearance he wants.

Range Coding

A set of vertical code bars mark the first range and at the option of the pilot, one of the 3rd, 4th, 5th, or 7th ranges can be coded as an aid to interpretation and provides a predetermined reference point for flying the display of terrain. The 10-range increments present specific range information as shown in figure 9-18.

SRTC Scaling

When the VDI is in contact analog (CA), the horizon and all symbols are computer scaled to ±30°. With terrain clearance (TC) selected, the horizon and terrain are scaled in the radar data converter, while the VDI navigation and attack symbols are still computer-derived and scaled to ±30°. Terrain clearance video is scaled to approximately 27° (±13.5°) vertically, and 52° (±26°) horizontally.

The TC horizon is scaled to 30° in a climb (or pullup) and 15° in a dive. The change in scale occurs when the horizon is at the VDI vertical center. In most normal flight attitudes or on the ground, there should be no change in the horizon position when selecting TC from contact analog. Tracking circuits provide for correct positioning of terrain for all attitudes within the pitch (±30°) and roll (60°) limits of the antenna.

TC Scaling	CA Scaling
Terrain video	
±13° vertical	±30° (symbols)
±26° horizontal	horizon ±30° (symbols)

In aircraft with the modified SRTC mode, the radar altitude curtain which is positioned by a signal from the radar altimeter, presents an analog of aircraft altitude. The curtain, like the radar altimeter, operates between the altitudes of 20 feet and 5,000 feet. The position of the curtain between the horizon and the bottom of the scope varies with aircraft altitude, attitude, and the altitude scale factors which are displayed below:

Altitude	Displacement Below Horizon Line
0 feet	0 inches
0 to 400 feet	175 feet/inch
400 to 5000 feet	1340 feet/inch

When the top of the radar altitude curtain is matched with the offset impact bar positioned 1 3/4 inches below the horizon line, the altitude of the aircraft is 275 to 325 feet AGL.

E-SCAN MODE

When elevation scan (E-SCAN) is selected, the track radar is used to provide a vertical display of terrain elevation along the aircraft flightpath on the PHD. The track radar antenna scans a sector in elevation of + 10° to - 15° relative to the flightpath vector. When the computer is operating the scan is oriented in azimuth to the aircraft ground track and when the computer is off, to aircraft ADL. Figure 9-19 depicts an E-scan display. The pilot can select a clearance line of 200, 500, or 1,000 feet and a range of either 5 or 10 miles. Range marks are displayed every 2.5 miles.

In earlier models of the A-6 aircraft, when a portion of the terrain appeared above the clearance line, it indicated that the aircraft will clear the obstacle by less than the amount selected. Similarly, if terrain video projects above the flight line, the aircraft will collide with the obstruction unless the flightpath is changed.

After the incorporation of an AVC in later model aircraft, the clearance line is a display of the radius of curvature required to clear an obstruction by the amount selected. The line is defined by the clearance selected and a 2-g pullup at 350 KIAS. Terrain video appearing to the left of this line will be cleared by less than the amount selected. If terrain video is to the left of the clearance line and above the flight line, the aircraft will collide with the obstruction unless the flightpath is changed.

RANGE LINES	PHD CONTROL BUTTON	RANGE INCREMENT REPRESENTED	TERRAIN FEATURES	TRACKING POSITION OF OFFSET IMPACT BAR	RESULTANT CLEARANCE (FEET)
1		¼ to ½ (PERM. CODED)			
2	1	½ to ¾	FLAT PLAINS	BOTTOM OF FIRST SELECTABLE INCREMENT	400 to 600
3	1	¾ to 1	ROLLING PLAINS	TOP OF FIRST SELECTABLE INCREMENT	600 to 900
4	2	1 to 1½	HILLS	TOP OF SECOND SELECTABLE INCREMENT	900 to 1050
5	3	1½ to 2	HILLS	TOP OF THIRD SELECTABLE INCREMENT	1050 to 1600
6	4	2 to 2½	HILLS	BOTTOM OF FOURTH SELECTABLE INCREMENT	1600 to 2000
7	4	2½ to 3	HILLS	TOP OF FOURTH SELECTABLE INCREMENT	GREATER THAN 2000
8		3 to 4			
9		4 to 6			
10		6 to 8½			

NOTE

1. The offset impact bar is measured downward from the center of the VDI.
2. Hills are defined as terrain having a differential altitude of approximately 700 feet.
3. Increasing severity of terrain features will decrease the resultant clearance when using listed tracking positions.

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Figure 9-18.—SRTC operating parameters.

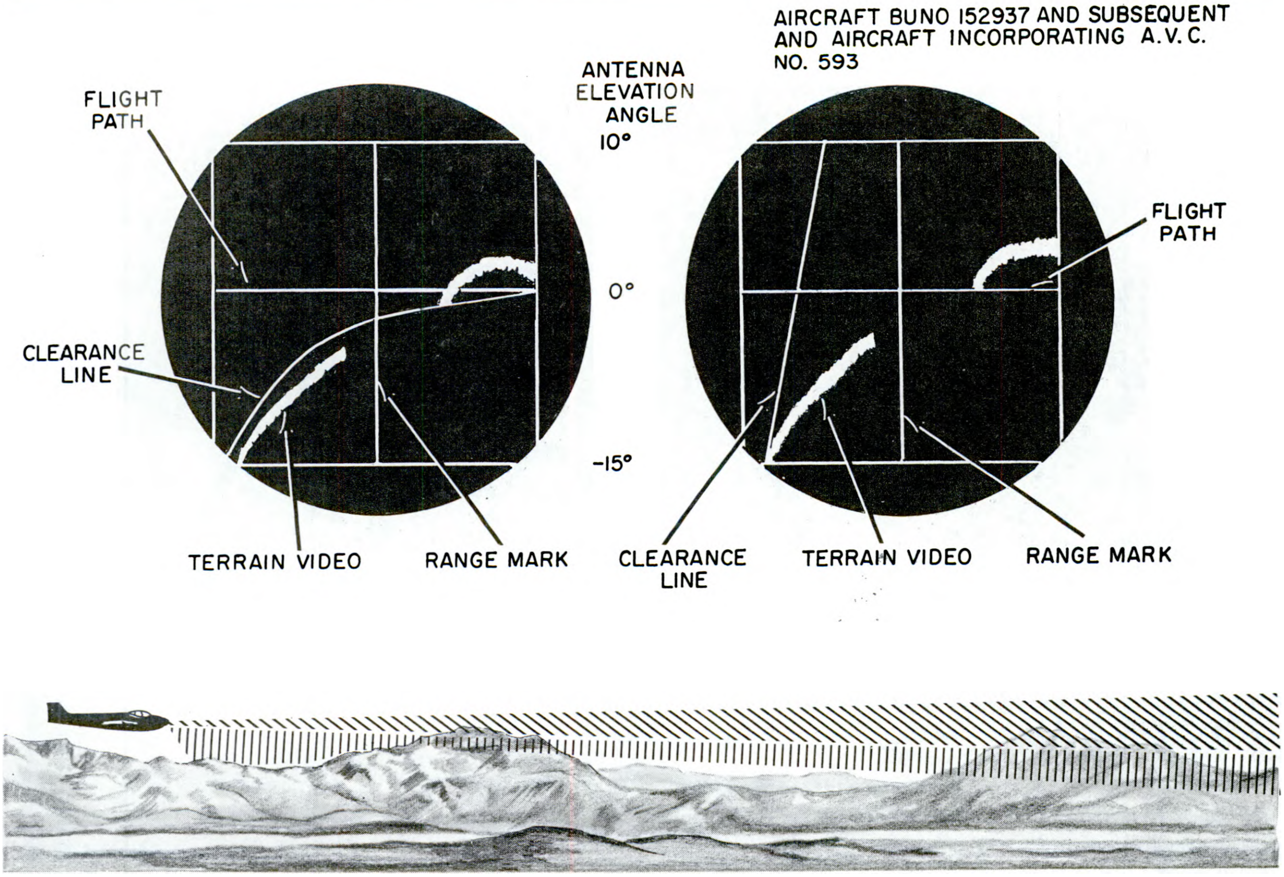

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Figure 9-19.–Terrain clearance (E-scan).

A flight technique for E-scan that has been found to be usable is one that is based on control of the aircraft velocity vector referenced to E-scan video patterns. An aid for accomplishing this control is a line on the display which approximates a desired speed and g combination or radius of curvature required to obtain a desired clearance altitude. The rule for this technique is to fly pitch control to keep E-scan video on or to the right of this transition line. The transition line here discussed is the clearance line displayed in aircraft with the modified E-scan. A method which proves to be practical for drawing the transition line on the display in aircraft not incorporating the modified E-scan is as follows:

1. Display the 5 NM E-scan with a 500-foot clearance line.
2. Estimate the 1 NM range at the top of the display and connect this point with the point at which the 500-foot clearance line intersects the bottom of the display scan.

TERRAIN CLEARANCE–PLAN POSITION INDICATOR (TCPPI)

The terrain clearance plan position indicator (TCPPI) mode of operation of the track radar provides the pilot and the B/N to a depressed center PPI display of terrain close to the flightpath of the aircraft. The track radar beam is depressed 1^{0} below the flightpath and scans an angle of approximately 30^{0}. The displayed range of the presentation is either 5 or 10 miles, selectable with the display scale switch on the pilot's control panel. One range line is displayed at 2.5 miles. Scan angle is centered about the ground track when the ballistics computer is operating, and about the ADL when the computer is off.

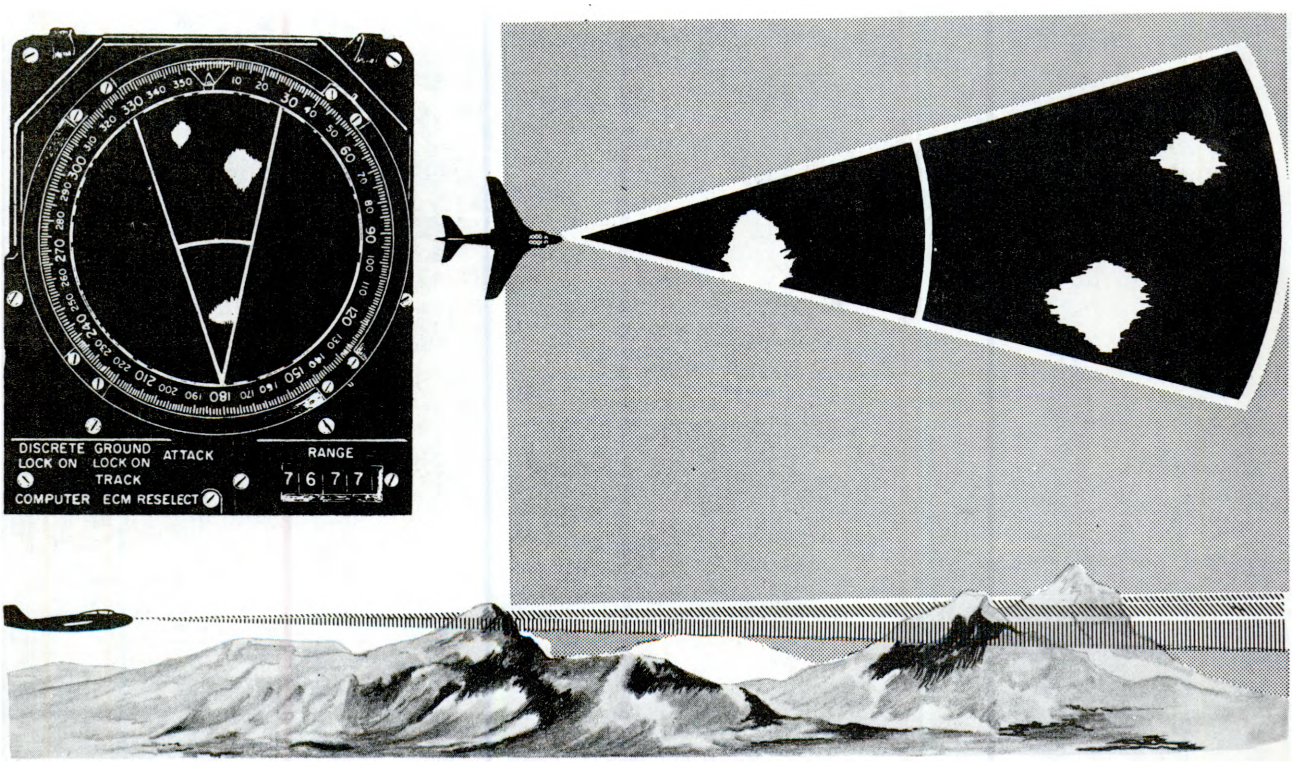

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Figure 9-20. –Terrain clearance (PPI).

In figure 9-20, a typical TCPPI display is illustrated. Note that the aircraft is flying through an area dotted with terrain peaks at some height above the intended flightpath of the aircraft. The aircraft can now be controlled so that a new flightpath develops around or over the obstacles, as elected by the pilot.

EMERGENCY SEARCH

The emergency search (EMER SRCH) track radar display serves as a backup for the search radar in the event of search radar failure. The esentation is a depressed center PPI display h approximately 30° of azimuth scan, with ntenna elevation angle manually controlled B/N. Since the elevation angle determines the range at which the beam intersects the ground the B/N can vary the area being searchlighted by manipulating the track radar elevation slew switch on the slew control. The displayed range of the presentation is either 5 or 10 miles, selectable with the display scale switch on the pilot's control panel; however, unlike the TCPPI display, there is no range line on emergency search.

Limitations of Emergency Search Mode

The emergency search mode of operation has certain inherent limitations. In contrast to the search radar presentation, range and azimuth resolution are poor. Maximum range is 10 miles, and the illuminated area decreases with an increase in altitude. However at low altitudes the presentation still affords adequate definition for identification of prominent points; i.e., bridges, rivers, shorelines, and small towns. The area scanned by the track radar in the emergency search mode can be increased in azimuth by placing the search radar power switch to STBY and tilting the B/N's slew grip to the left or right. This will cause the track radar to scan a 30° sector to the right or left of the aircraft. However, the presentation will remain centered on the DVI and PHD, regardless of the displacement of the track radar antenna in azimuth.

Options for Selection

The emergency search display is presented on both the DVI and PHD; however, it is selectable only by the B/N. In addition, the horizontal display mode selector switch must be in SRCH in order for it to be displayed on the PHD. If the mode selector is placed to the TCPPI or EMER SRCH position, the selected display will be presented on the PHD and the DVI will no longer have an emergency search display even though it was selected on the B/N's control panel. The selection of a track radar display on the PHD preempts the selection of an incompatible display on the DVI.

A-6A TERRAIN CLEARANCE

Figure 9-21 illustrates the various terrain clearance displays available, on which indicator(s) it is displayed, the sweep length, and the operating range in each of the four modes.

PRESENTATION	DISPLAYED ON	PRIMARY USE	SWEEP LENGTH (NM)	OPERATING RANGE (NM)	SCAN ANGLE (AZ)	FIXED RANGE MARKERS	REMARKS	
T/C	VDI	TERRAIN AVOIDANCE	8.5	0-8.5	60°-114° EL: +10° OR -15° OF FLIGHT PATH AXIS		FOR OPTIMUM DISPLAY PPI-30 OR ARE	
E-SCAN	PHD	TERRAIN AVOIDANCE	5 OR 10	0-10	10° ABOVE TO 15° BELOW FLIGHT PATH	EVERY 2.5 MILES	PRESENTATION SHOWS CLEARANCE IN THE VERTICAL PLANE.	SCAN CENTER IS GROUND TRACK, WHEN COMPUTER IS OPERATING. IF COMPUTER IS OFF, NO DRIFT INFORMATION IS AVAILABLE AND SCAN CENTER IS DEAD AHEAD.
TCPPI	PHD/DVI	TERRAIN AVOIDANCE	5 OR 10	0-10	30°	2.5 MILES	RADAR SHOWS TERRAIN WHICH PROTRUDES ABOVE THE FLIGHT PATH.	
EMERG SEARCH	PHD/DVI	TERRAIN SEARCH	5 OR 10	0-10	30°	NONE	ANTENNA IS MANUALLY CONTROLLABLE IN ELEV.	

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Figure 9-21. –A-6A terrain clearance radar displays.

CHAPTER 10

RADAR INDICATORS

This chapter is devoted to a detailed discussion of the various types of indicators which the Aviation Fire Control Technician may be required to maintain. The technician should find a knowledge of their construction and operating principles very helpful in the performance of fire control maintenance.

INDICATORS

The purpose of the indicator and its associated components is to display target information supplied by the receiver and antenna system. The indicator may be a relatively simple device such as an indicating light that goes ON and OFF when specific conditions exist, a small meter, or an elaborate assembly containing a cathode-ray tube (CRT). However, in any case the complexity of the indicating system will vary with the amount of information to be displayed to the operator.

The two types of radar indicators discussed in this chapter are the CRT and the direct view storage tube (DVST). These indicators may also very in degree of complexity and may be used to display numerous data simultaneously to the operator. Some of the data presented to the operator are as follows:

1. Target range.
2. Range rate.
3. Target position (relative).
4. Artificial horizon.
5. Steering references.
6. Altitude.

This list, however, should not be construed as being all inclusive.

CATHODE-RAY TUBE

As an Aviation Fire Control Technician, you should be familiar with the CRT and its use in various oscilloscopes and test equipments. However, the construction and the operation of the CRT are briefly reviewed in this chapter. Nevertheless, it is recommended that the section pertaining to the CRT in chapter 9 of Basic Electronics, NavPers 10087-B, be reviewed before continuing further in this chapter.

CRT's are used in radar equipment to display visually target information. Although there are several types of CRT's, all contain the following.

1. An electron gun which projects a fine beam of electrons on a screen.
2. A deflection system.
3. A fluorescent screen which changes the energy contained in the beam into light.
4. An evacuated glass envelope.

The beam of electrons may be deflected by an electric field or a magnetic field. Thus the deflection types are electrostatic and electromagnetic.

Electrostatic CRT

Most vacuum tubes have one common feature–a centralized cathode surrounded by various other elements. The electrons emitted from their cathodes are sent out radially in all directions. However, the electrons emitted from the cathode of a CRT are confined to a parallel beam by means of what is commonly called an electron gun.

The electron gun consists of a cathode, a grid which tends to concentrate the electrons into a beam, and anodes which accelerate and focus the beam of electrons.

The cathode of a CRT is indirectly heated and consists of a small metal thimble inside of which is mounted the heating element or filament. To make the cathode a good emitter when heated, the front end is oxide coated as shown in figure 10-1. It should be noted that emission is from the front end only.

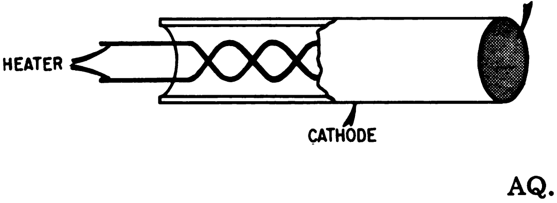

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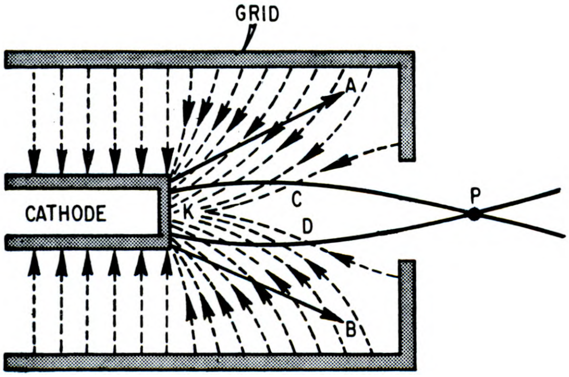
Figure 10-1. –Filament and cathode of a CRT.

The filament, which is made of tungsten wire, is wound in a double spiral so that the electron beam will not be affected by the applied a. c. In this way the magnetic field of one-half the filament is canceled by the equal and opposite field of the other half. The filament is electrically insulated from the cathode. However, the insulation does touch the cathode to provide good head conduction.

The grid is essentially a metallic cylinder in the form of a cap which surrounds the cathode and has a small hole in the end. The potential applied to the grid is negative in respect to the cathode and, as a result, an electrostatic field is developed between the two as shown in figure 10-2.



AQ. 168

Figure 10-2.–Electrostatic field between grid and cathode.

An electron that starts out in the direction of KA is bent by the lines of force so that it takes the path KCP. In a similar fashion, the electron which starts out in the direction KB is bent so that it takes the path KDP. Thus, the paths of these two electrons intersect at P. Most of the electrons which pass through the hole in the grid are concentrated in this manner into a beam of electrons.

The lines of force between the grid and cathode prevent the emitted electrons from diverging outward from the cathode and cause them to bend inward along the axis of the electron gun. They may even cause the electrons to cross over and diverge on the opposite sides. The grid of the CRT also controls the number of electrons in the electron beam in a manner similar to the action of a grid in a conventional vacuum tube. Therefore, the grid of the CRT performs two functions: (1) it controls the number of electrons which are allowed to pass through the hole, and (2) it acts as a lens which tends to concentrate the electrons into a beam.

One of the factors controlling the intensity of the spot on the fluorescent screen is the number of electrons in the beam. The number of these electrons, as stated previously is controlled by the difference in voltage between the grid and cathode or grid bias. Most CRT's utilize a potentiometer to vary the bias on the grid, thus enabling the operator to control the brightness of the spot. This potentiometer may be known by several different names such as intensity, brilliance, or brightness control.

In addition to the grid and cathode, the electron gun also contains two anodes. The construction of the anodes is similar to that of the grid. The first anode, sometimes called the focusing anode, is closer to the grid and is positive by a few hundred volts in respect to the cathode. The second anode or accelerating anode is next in line and is at a much higher positive potential than the first anode.

As shown in figure 10-2, the electron beam is in focus at point P which is close to the grid. However, the beam must also be in focus when it strikes the screen. This is accomplished by the electrostatic field between the two anodes. (See fig. 10-3.)

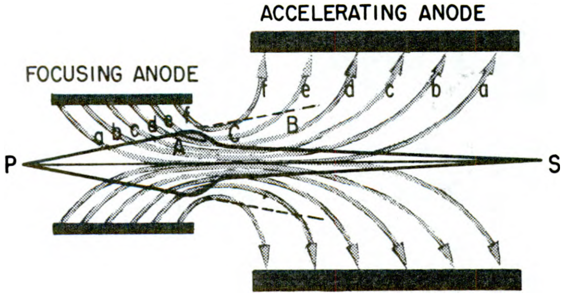


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Figure 10-3.–Electrostatic field between the first and second anode.

An electron introduced into the field at point P would tend to follow one of the lines of force and hit the more positive anode. Because of the high voltage on the anodes, the electron travels at an extremely high velocity and does not remain in the field long enough to be pulled completely off its course. But it is subjected to forces as it moves through the field. For example, an electron which is traveling from point P along the path PAB is curved toward the axis by the lines of force and thus takes the path PAC. In the center, the lines of force are nearly parallel to the axis and in the direction of point S. Therefore, the beam of electrons is accelerated in the direction of point S.

The point where the electrons converge may be shifted by varying the strength of the field between the two anodes. This is done by a potentiometer which varies the voltage on the first anode. This control is sometimes called the focus control.

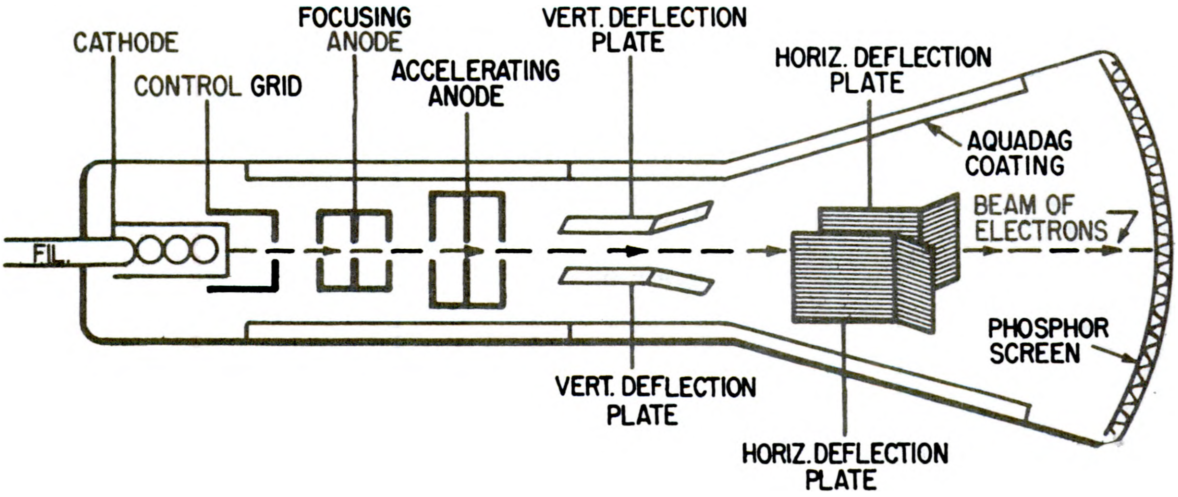
The screen is made fluorescent by a coating of materials deposited on its inner surface. These materials, called phosphors, emit light when struck by a beam of rapidly moving electrons. The color and persistence of the light depend upon the composition of the particular phosphor used. Phosphors are designated by the letter P followed by a number which indicates its persistence. These numbers presently fall between 1 and 31 but bear no relationship to the time an image will persist on a screen. However, most aviation fire control radar indicators use CRT's with long persistence.

CRT screens vary in size, color, and persistence. The most common size CRT screen used in aviation fire control radar is approximately 5 inches in diameter. Manufacturers indicate the size by using the size in inches as the first digit in the tube's designation.

The electrons reaching the screen give up energy in producing luminescence. When this is accomplished, they must be removed or a large negative charge would develop on the screen. Thus, some method must be used to return the electrons to the power supply. Since the electrons striking the screen are traveling at a very high speed, they cause other electrons to be emitted (called secondary emission). The aquadag coating, which consists of a conductive material deposited on the flare of the CRT, is connected to a very high voltage. (See fig. 10-4.) Much of the secondary emission is attracted by this high potential. Thus, the electrons are returned to the power supply. The aquadag coating also serves as a shield for the electron beam.

The deflection plates are the final components necessary to complete the electrostatic CRT. There are two pairs of deflection plates which are set at right angles to each other, and the electron beam passes between all four of the plates. The plates are called vertical and horzontal deflection plates according to the direction in which they deflect the beam and not according to the manner in which they are mounted. Figure 10-4 illustrates the mounting of deflection plates.

The amount of deflection caused by a set of deflection plates depends upon the velocity of the electron beam, the voltage applied between the plates, and the spacing of the plates. A measurement of this deflection is called deflection sensitivity. Deflection sensitivity is defined as the number of centimeters the spot on the screen will be deflected when 1 volt is applied to the deflection plates. Thus, a deflection sensitivity of 0.22 cm/volt means that



AQ. 170

Figure 10-4. –Electrostatic CRT.

each volt d.c. applied between the plates causes a deflection of 0.22 cm.

A more useful measurement of deflection sensitivity is known as deflection factor-measured in volts per centimeter or volts per inch. This factor indicates the voltage that must be applied between the plates to obtain a deflection of 1 cm or 1 inch. Tube manuals give the deflection factor in volts per inch.

Electromagnetic CRT

The electron gun of the electromagnetic CRT is very similar to the electron gun found in the electrostatic type of CRT. However, there are some differences in the two types which are primarily in the method of focusing and deflecting the electron beam. As the name implies, focusing and deflection are by electromagnetic fields.

In this type CRT, the first anode (after the control grid) serves as the accelerating element rather than as the focusing device. The second anode (rather than being the accelerating anode as in the electrostatic CRT) is the aquadag coating with a high positive potential applied to it. It serves the same purpose as aquadag coating in the electrostatic type CRT. However, it does aid in accelerating the electrons and may sometimes be referred to as an accelerating anode.

The focusing coil of the electromagnetic CRT replaces the second anode and performs the same function as the first anode in the electrostatic CRT. The deflection coils, or deflection yoke as it is sometimes called, replace and perform the same function as the deflection plates in the electrostatic type CRT. Figure 10-5 is an illustration of the complete basic electromagnetic CRT.

The focusing coil is essentially an electromagnet which fits around the neck of the CRT as illustrated in figure 10-6. When a d-c current flows through the windings of the coil, a magnetic field is set up, part of which is within the neck of the tube. It should be noted that within the neck the magnetic lines of force have a mean direction which is along the axis of the neck. Thus, the magnetic field causes the electron beam to converge. The amount of current in the coil may be controlled by a rheostat (focus control), thus controlling the strength of the magnetic field.

The manner in which the electron beam is focused may be explained with the aid of figure 10-6. Point P is the crossover point which the electron beam is assumed to have reached after being emitted by the cathode, acted upon by the grid, and accelerated by the first anode.

The electrons traveling down the axis of the tube will not be affected by the magnetic field. Those electrons traveling at a small angle will have a force applied to them perpendicular to the magnetic field. This force will tend to bring the electrons back into the line of travel. This action, however, could cause the electrons to oscillate back and forth across the neck of the tube and gradually damp out. As shown in figure 10-6, an electron traveling along the line PAB

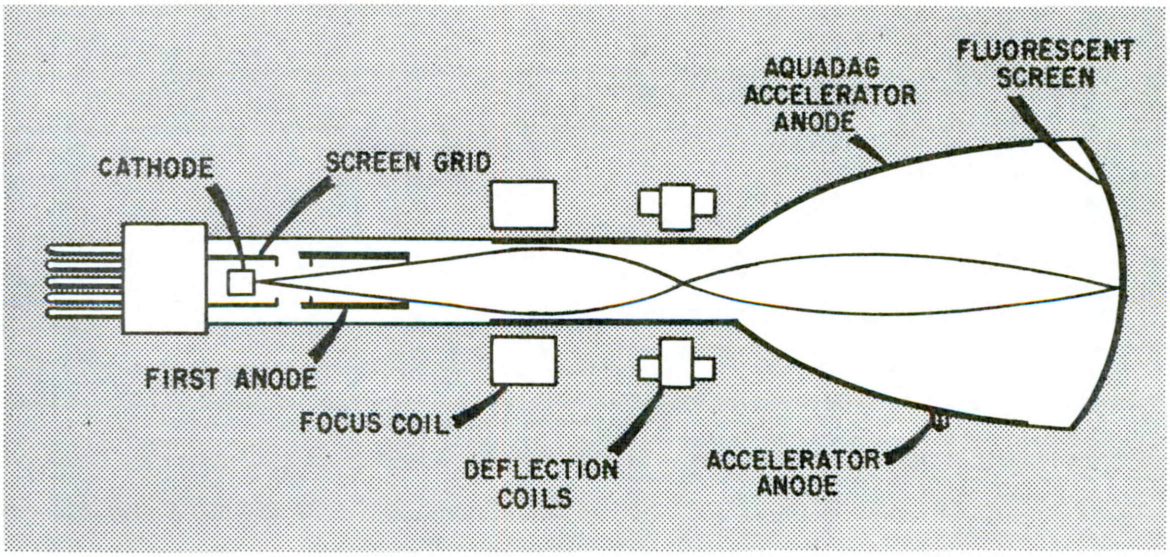


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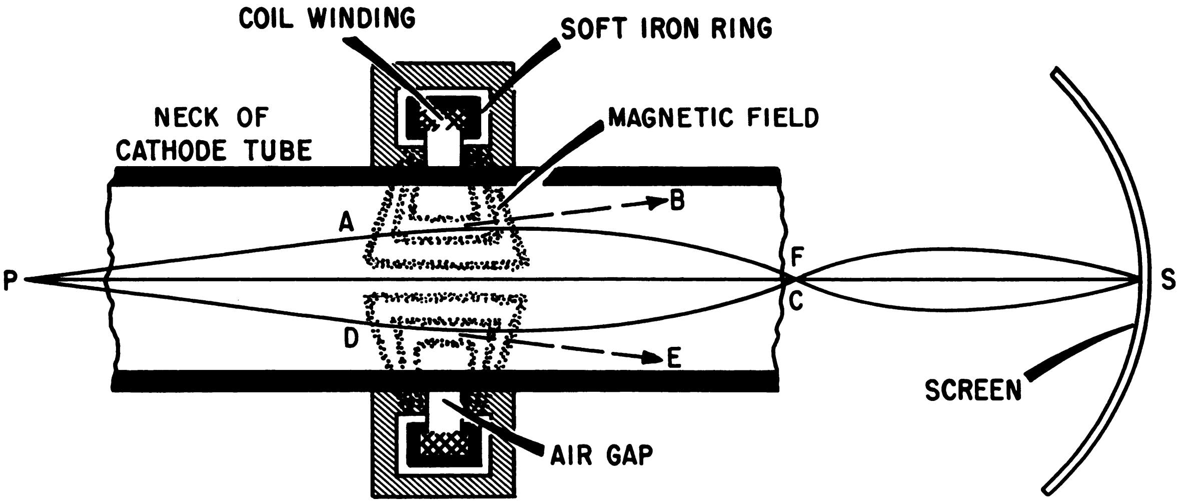
Figure 10-5.–Electromagnetic CRT.



AQ. 172

Figure 10-6. –Electromagnetic focusing.

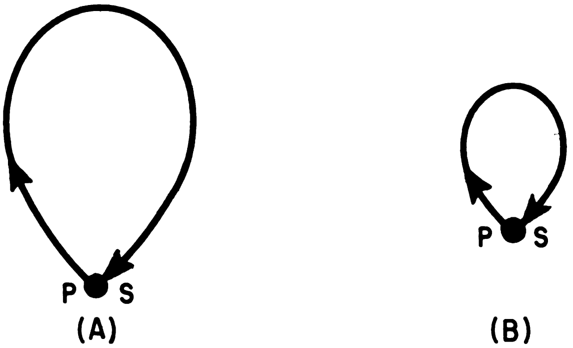
or PDE would be forced by the magnetic field to take the paths PACS and PDFS, respectively. All electrons coming from the crossover point P and entering the magnetic field follow paths that make them meet at the common point S.

However, it is possible that an electron could be traveling off to one side or the other as well as at an up or down angle. Thus, the magnetic field could be acting on the electrons in more than one direction at one time, which would effectively result in a spiral path of travel by the electrons, as illustrated in figure 10-7. If you could look down on the face of the scope and see the paths of the electrons, you would see spirals such as these. Spiral (A) is the path of an electron that entered the magnetic field at a greater angle than in spiral (B). However, it travels faster and they both reach point S at the same time. In order to focus the beam, it is only necessary to adjust the strength of the magnetic field so that the common point S falls on the fluorescent screen.

Although we have considered using only electromagnets for focusing, a permanent magnet can perform the function equally as well. Some CRT indicators found in aviation fire control equipment (predominant in bomb director sets) utilize permanent magnet focusing devices. The permanent magnet encircles the neck of the CRT in a manner similar to the focusing coil.

Focusing of the electron beam is accomplished by moving the magnet along the axis of the tube until the beam of electrons is sufficiently concentrated at the face. Another means of adjusting the focus of an electron beam with a permanent magnet would require the use of a shunt. The shunt would be adjusted to increase or decrease the concentration of magnetic flux in the neck of the CRT.

Electromagnetic deflection is sometimes more desirable and offers some advantage over electrostatic deflection. One big advantage is



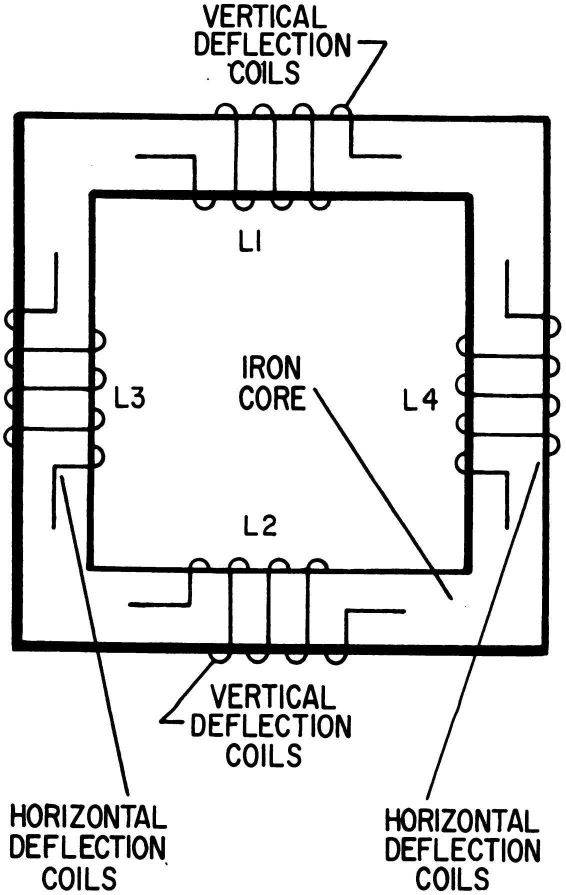
AQ.173

Figure 10-7.--End view of electrons' paths.

that tube construction is simpler since there are no deflection plates within the tube. Another advantage is that high amplitude deflection voltages are not required since it is a current operated device.

To understand electromagnetic deflection of an electron beam in a CRT it is essential that the Aviation Fire Control Technician understand the properties and characteristics of current carrying conductors, their magnetic fields, and the interaction between two or more magnetic fields. (NOTE: A beam of electrons moving in one direction has essentially the same properties as d.c. flowing through a conductor.) A review of chapter 7 in Basic Electricity, NavPers 10086-B, is recommended before continuing further.

The electromagnetic deflection method most commonly used in aviation fire control equipment employs the stationary deflection yoke. A schematic of the yoke is shown in figure 10-8.


VERTICAL DEFLECTION COILS
L1
L3
IRON CORE
L4
L2
VERTICAL DEFLECTION COILS
HORIZONTAL DEFLECTION COILS
HORIZONTAL DEFLECTION COILS

AQ. 174

Figure 10-8. –Basic Illustration of a stationary deflection yoke.

As illustrated, the deflection yoke consists mainly of an iron core and two sets of deflection coils mounted at right angles to each other. One set provides vertical deflection of the electron beam and the other horizontal deflection. Each coil is composed of many turns of wire, and the coils of each set are connected so that the magnetic fields set up by each pair of coils travel in the same direction and parallel across the neck of the CRT.

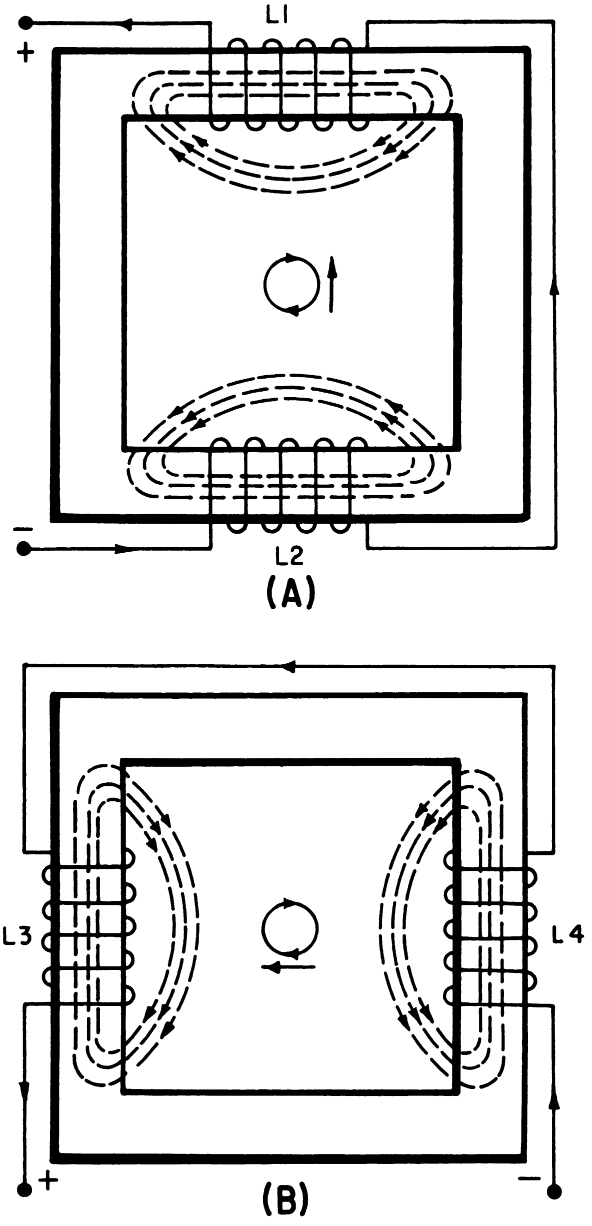
The two coils of each set are wound in series opposition to each other on the iron core. Thus, since the flux produced by each is in opposition (within the iron core), the only way in which the lines of force can form closed loops is by crossing the neck of the CRT. By using two sets of coils in this manner, two magnetic fields can be set up across the neck of the CRT which are at right angles to each other. Figure 10-9 is an illustration of the two sets of deflection coils and their respective magnetic fields.

In both (A) and (B) of figure 10-9 it should be noted that the electron beam is coming out of the paper. Thus, the magnetic field around the beam is moving clockwise. As shown in (A) of figure 10-9, the magnetic flux set up by L1 covers the upper half of the tube's neck and is in opposition to the flux around the electron beam. The magnetic flux covering the lower half of the tube's neck is established by the current flowing through L2 and is traveling in the same direction as the lines of force around the electron beam. Since lines of force in opposite directions cause attraction between the sources, and lines of force in the same direction cause repulsion, the flux's resultant force on the electron beam is in an upward direction. Thus the beam will be deflected in an upward direction. Therefore, it can be seen that an electron moving prependicular to a magnetic field is deflected at right angles to its path and to the field.

If the direction of current flow through the windings L1 and L2 is reversed, the direction of the flux set up by each will also be in the opposite direction. With the magnetic flux around the beam unchanged, the resltant force acting on the electron beam will also be in the opposite direction. Therefore, the electron beam will be deflected in a downward direction.

The speed at which the electron beam will be deflected across the screen of the CRT will be dependent upon the rate of change of current flow in the windings. The maximum distance that the electron beam will be deflected will be dependent upon the amount of magnetic flux established by the coils.

Part (B) of figure 10-9 is an illustration of a set of coils similar to the coils illustrated in part (A) except that they are oriented to deflect the beam in the horizontal plane. Deflection of the electron beam is accomplished by coils L3 and L4 in a manner similar to the deflection in the vertical plane by coils L1 and L2. As illustrated, the electron beam is deflected to the left; but if the current through the coils is reversed in direction, the beam will be deflected in the opposite direction across the screen of the CRT.



AQ. 175

Figure 10-9–(A) Vertical Deflection; (B) horizontal deflection.

Thus far the vertical and horizontal deflection coils have been discussed separately. However, if they were wound on the same iron core and energized simultaneously, the electron beam could be deflected in directions other than in the vertical and horizontal plane. The operation of the stationary electromagnetic yoke is based on this principle.

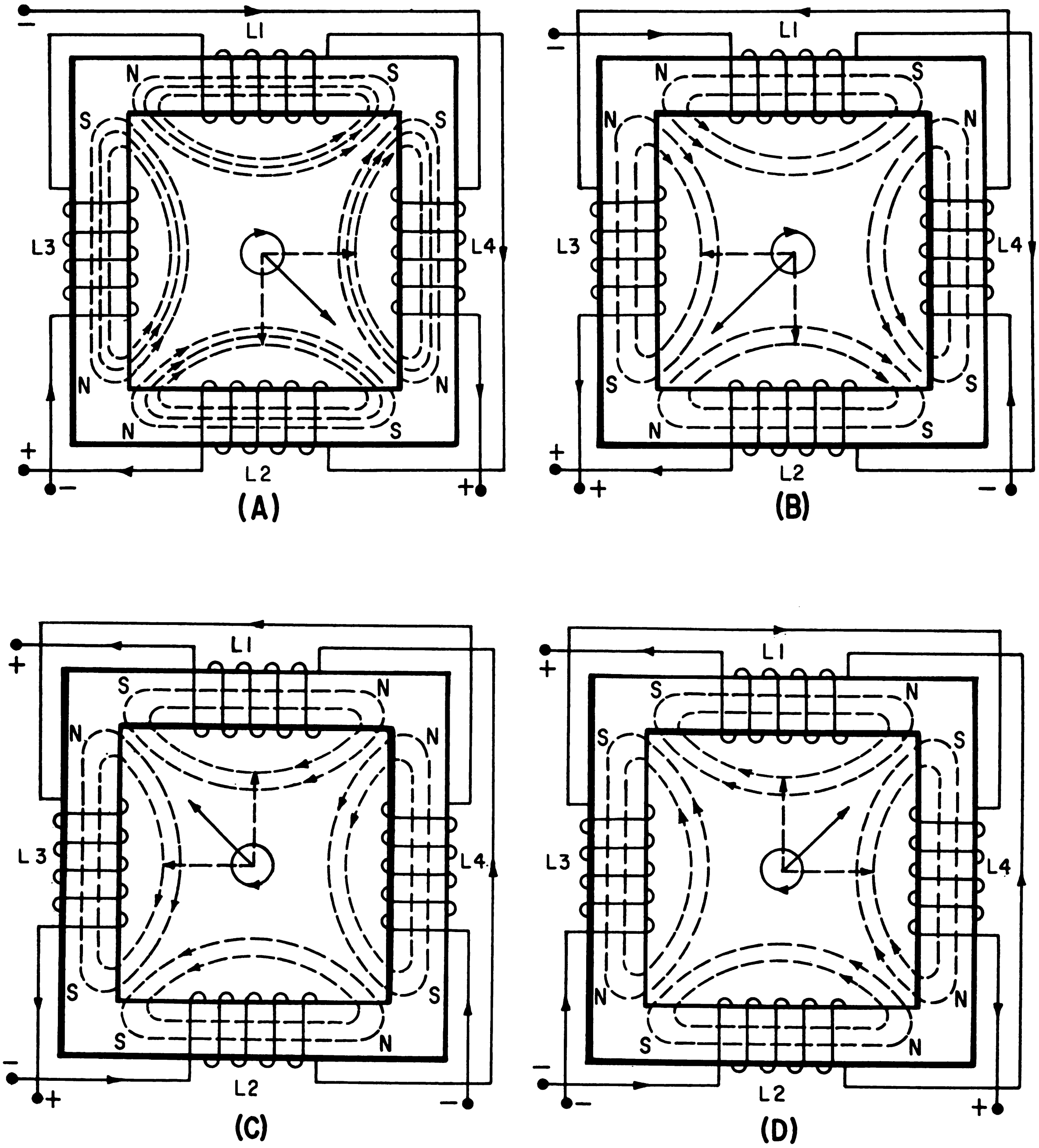
Figure 10-10 can be used to further illustrate the operation of the deflection coils and how the electron beam can be deflected in various directions. The electron beam is coming out of the paper, and the amplitude of the current through each coil is the same for each illustration in figure 10-10.

When current flow through L1, L2, L3, and L4 is as shown in figure 10-10(A), the beam will be deflected in the direction indicated. The direction of the movement is the resultant of the vertical and horizontal forces acting on the electron beam which is illustrated by broken lines. Since each of the forces is equal, the resultant force is 45° from or halfway between the two.

If current continues to flow in the same direction in L1 and L2, but is reversed in the horizontal coils L3 and L4, the effect will be as shown in (B) of figure 10-10.

With the current continuing to flow in the same direction through L4 and L3 but reversed in L1 and L2, the deflection of the electron beam will be in the direction as illustrated in (C) of figure 10-10. Reversing the current through L3 and L4 again, but leaving L1 and L2 unchanged, will cause the electron beam deflection to advance another 90° around the screen of the CRT. (See fig. 10-10 (D).)

In summary, it should be recalled that current flow in the vertical deflection coils only, produced either an upward or downward deflection of the electron beam, depending on the direction of current flow. The same was true of the left or right deflection produced by current in the horizontal deflection coils. When the current flow through the two sets of deflection coils was equal, the deflection of the electron beam was 45° from the vertical and horizontal planes. However, the quadrant in which the beam was deflected depended on the direction of current flow through the coils.



AQ. 176

Figure 10-10. –Deflection yoke.

It should be noted that as the current in each set of coils was reversed consecutively, one after the other, the trace produced by the electron beam advanced around the screen of the CRT by an angular amount of 90°. However, to have one type of scope presentation (a PPI-type scan), the trace on the screen must appear to be continuously rotating about the center axis of the CRT. This can be accomplished by varying the amplitude of the deflection currents applied to each set of deflection coils at a sine wave rate, but the amplitude variations in one pair of coils must be 90° out of phase with those in the other pair.

The synchro resolver, sometimes called a sweep resolver, is normally used in aviation fire control equipment to provide currents of the proper value and relationship to produce a rotating sweep.

Figure 10-11 is a schematic of a sweep resolver, the rotor of which is positioned in synchronism with the antenna. The sweep voltage from the sweep generator located in the synchronizer is applied to the rotor winding. The output amplitude and polarity from each of the stator windings will depend upon the relative position of the rotor.

If the antenna is pointing dead ahead at 0° azimuth, the vertical deflection of the electron beam must be maximum upward and the horizontal deflection must be 0. At 90° or 270° azimuth, the vertical deflection must be 0 and the horizontal deflection maximum either left or right. Thus, the outputs of the stators are as follows:

Stator 1 (to horizontal deflection coils) $= E_{in} \times \sin \theta$

Stator 2 (to vertical deflection coils) $= E_{in} \times \cos \theta$

where θ is the antenna position.

Figure 10-12 is an illustration of the outputs from the two stator windings with the antenna rotating back and forth in azimuth between the limits indicated. It should be noted that the outputs vary at a sine wave rate 90° out of phase.

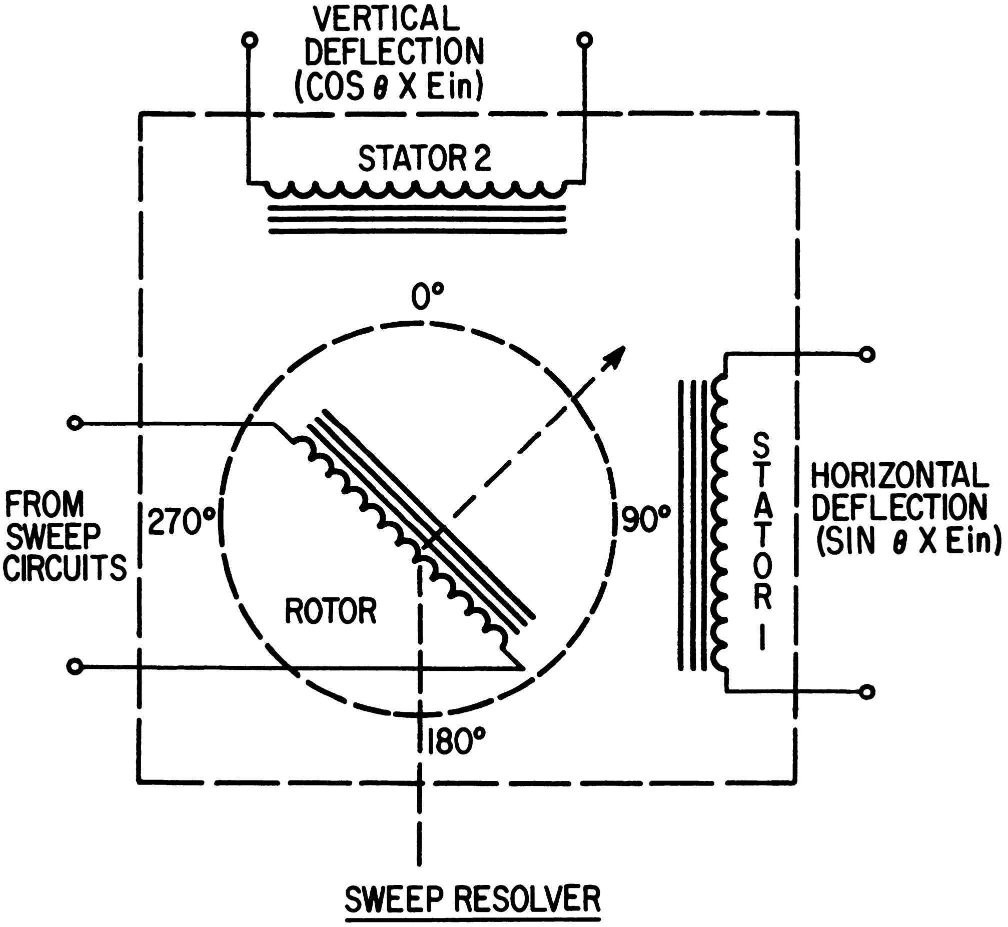
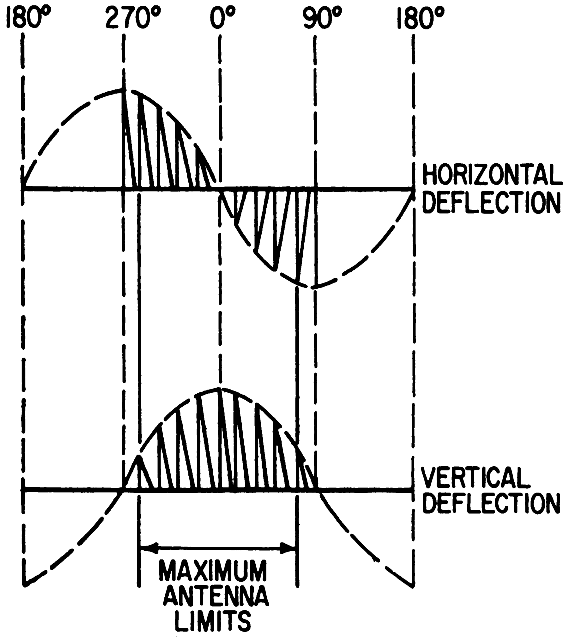


Figure 10-11. –Sweep resolver.

TYPES OF SCANS

The discussion of the various types of CRT's thus far has been limited to construction and operating principles. However, before the CRT can be of value in aviation fire control



AQ. 178

Figure 10-12.–Resolver outputs

equipment, it must be capable of presenting data to the operator.

The pattern that is produced by the scanning of the electron beam over the face of the CRT determines the type of scan. The basic terms to be used are defined below.

A sweep is the trace produced on the screen of the CRT by the linear deflection of the electron beam. The movement of the sweep across or around the screen of a CRT is called scanning. This movement is usually synchronized with the movement of the antenna which is also said to be scanning a certain area of space.

The type or types of scans employed by a radar are determined by the functions the radar performs. The four basic types of scans (A-scan, B-scan, C-scan, and PPI-scan) are discussed in chapter 12 of Aviation Fire Control Technician 3 & 2, NavPers 10387.

TYPICAL INDICATORS

The indicators employed in aviation fire control radar sets may vary considerably in construction, types of scans, and in operating principles. However, their operation may be reduced to one or more of the basic types of scans previously discussed. In this section, two typical radar indicators are discussed–the type normally found in bomb director sets and one typical of the various types used in aircraft fire control systems.

Bomb Director Indicator

A block diagram of the indicator is shown in figure 10-13. Note the various inputs to the indicator tube and to its deflection coil assembly. These inputs are the horizontal sweep waveform and the vertical sweep waveform. The intensity gate, azimuth line, and course marker pulses are applied to the control grid of the CRT. The video and range line pulses are applied to the cathode. The indicator high voltage (+4,800 volts) is provided by a special power supply normally located in the modulator unit.

The CRT is identical to the one discussed previously under magnetic deflection. However, the operation is summarized in the following paragraphs.

The control grid is at ground potential in static state and the cathode voltage may be varied between the approximate values of +25 and +75 (brilliance control) in respect to ground. Therefore, the grid bias may be set at any value between 25 and 75 volts. The first anode potential is +300 volts and the second anode potential is +4,800 volts.

A magnetic focusing ring of the permanent magnet type is located on the neck of the CRT. A second ring on the neck of the tube contains the deflection coil assembly. The coils in the assembly set up magnetic fields which position the electron beam in the same manner as that discussed earlier in this chapter.

Intercept System Indicator

A typical intercept system indicator utilizes a CRT containing three complete electron guns and their associated deflection systems. Each gun or portion of the CRT presents certain information during the various modes of operation. The information presented by the three electron guns in the search and track modes of operation is given in table 10-1.

The three electron guns contained in the CRT are referred to as the A-, B-, and C-guns but they do not necessarily provide A-, B-, and C-type scans. However, the B-gun does provide a B-scan in both the search and track modes of operation. The search and track displays illustrated in figures 10-14 and 10-15 should be studied in conjunction with table 10-1.

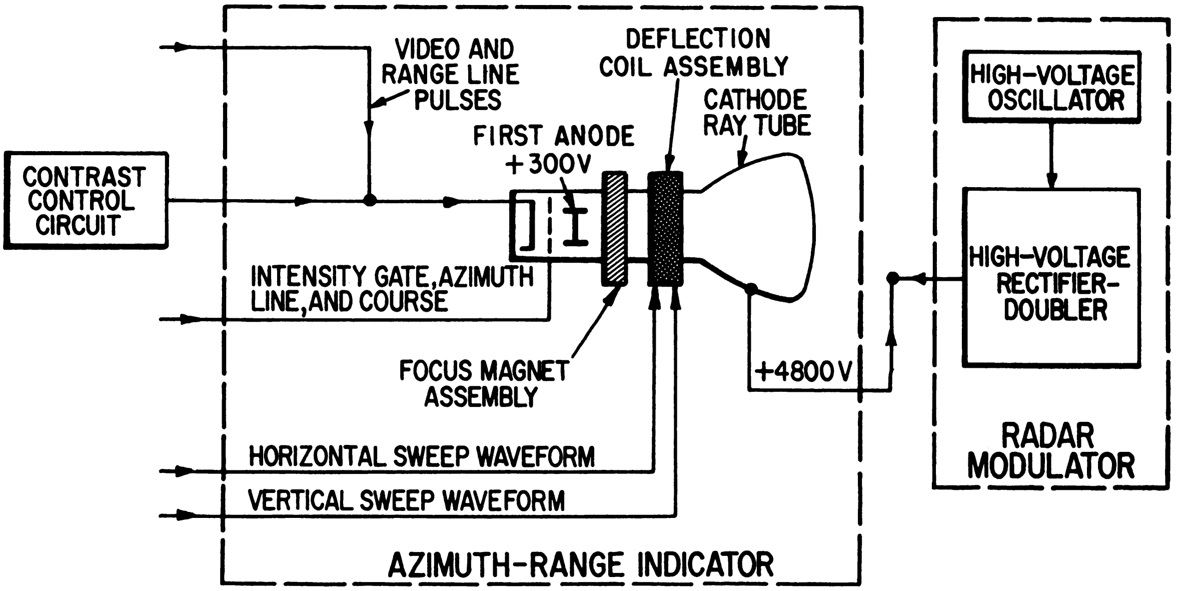


Figure 10-13.—Block diagram of a bomb director indicator.

To facilitate understanding the operation of the indicator, the terminology used in figures 10-14 and 10-15 is explained as follows:

Elevation strobe—Indicates degree of antenna tilt in relation to interceptor axis, as measured by etched elevation scale on right edge of the scope.

Range strobes—Parallel lines 1 mile apart, used to select a target for tracking. Pilot adjusts the range strobe until lines straddle target.

Artificial horizon—Provides indication to scope of interceptor attitude (climb or bank).

Altitude line—Ground-clutter return resulting from the side lobes of antenna radiation. Appears at range roughly corresponding to altitude of interceptor.

B-scan—Traces out on scope the azimuth motion of the antenna. Actual range to target is indicated by location of the target on the range sweep (vertical time base).

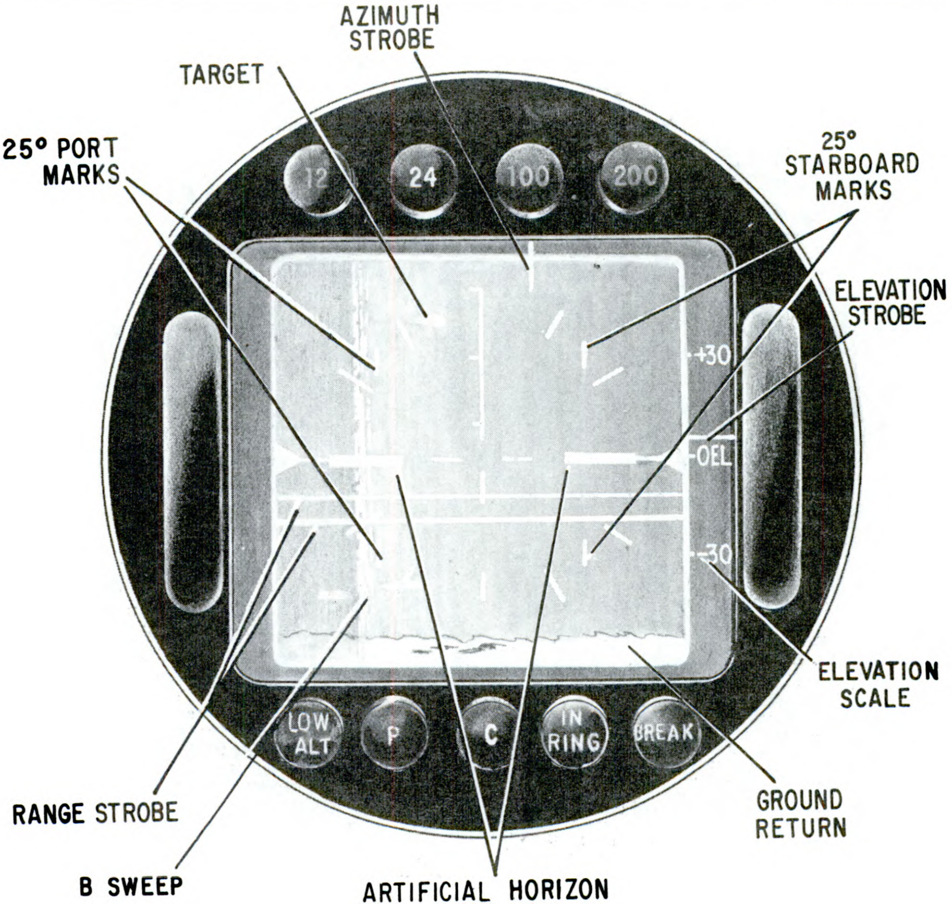
Azimuth-strobe—Indicates azimuth position to which antenna will slew when lock-on switch is pressed to begin automatic tracking. Position of azimuth strobe is changed by moving antenna controller.

Figure 10-16 is a schematic diagram of the multiple gun CRT that is discussed and should be referred to frequently. The circuitry common to all three of the electron guns will be discussed first.

Table 10-1.--Information presented by each electron gun for each mode of operation.

Electron gun	Mode	
	Search	Track
A-gun	Elevation strobe. Artificial horizon.	Range circle. Range rate gap. Artificial horizon.
B-gun	Azimuth and range (B-type scan). Range strobes. Targets.	Azimuth and range (B-type scan). Targets.
C-gun	Azimuth strobe.	Steering circle. Steering dot.

The aquadag coating of the CRT (V1) serves to collect the space charge and provide an accelerating voltage (8 kv) for all three of the electron guns. The cathode of each electron gun has a negative 3.85 kv potential applied from a common source. The second anode of each gun is connected in a similar manner to a variable positive potential. This potential may



AQ. 180

Figure 10-14. –Search presentation

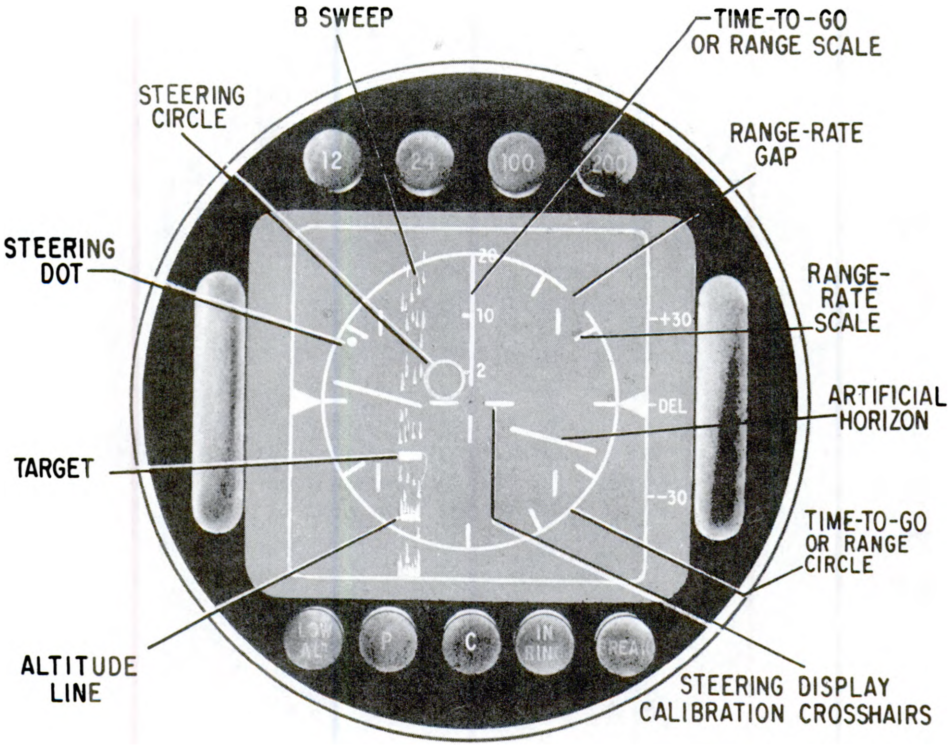
vary from 150 to 300 volts as determined by the setting of R28. This potential is set for best overall focus action of the three guns. Thus, each gun has the same applied accelerating voltage on their second and final anodes.

The B-gun intensity is controlled by R7 which determines the clamping level for the control grid. The focus control, R12, adjusts the voltage applied to the first anode of the B-gun. (See fig. 10-16).

The A- and C-guns utilize a single operator's control for their focusing. Their intensity is controlled in a similar manner. However, the circuits supplying the potentials for the focus and intensity controls contain additional balancing adjustments which the technician must make. It should be noted from table 10-1 and figure 10-14 and 10-15 that the intensity and focus of the two guns must be equal to insure that all information presented on the indicator will be equally visible to the operator.

Referring to figure 10-16, note that the control grids of the A- and C-guns are connected to R4 and R9, respectively. These potentiometers provide the technician with a means of adjusting the intensity of the A- and C-guns individually. The potentiometer R5B is connected in series with R4 and R9 and varies the voltage applied to the two controls. Thus, it is capable of controlling the intensity of the A- and C-guns simultaneously after the individual controls have been balanced.

The focus of the A- and C-guns can also be controlled individually by the setting of R22. Adjusting R22 must be done by the technician. It increases the voltage applied to the first anode (focusing anode) of one gun while it reduces the anode voltage of the other gun like amount. Thus, it must be set for equal focus of the two guns. Potentiometer R5A is in series with the potential applied to R22 and thus controls the focus of both the A- and C-guns simultaneously.



AQ. 181

Figure 10-15. —Track presentation.

In the discussion thus far the inputs to the control grids and deflection plates of the three electron guns have not been mentioned. The deflection plates of each gun are direct-coupled to the sweep generating circuits. However, the horizon line deflection signals are fed through an artificial horizon resolver and climb pot circuit to correct for the roll and climb of the aircraft.

NOTE: The sweep generating circuits used by radar sets of this type are discussed in detail in chapter 5 of this manual.

Each of the three control grid circuits contains a clamper to insure that the control grids are clamped at the same level for all inputs. The various blanking pulses, video pulses, and marker pulses are applied to the control grids to intensity modulate the three electron guns.

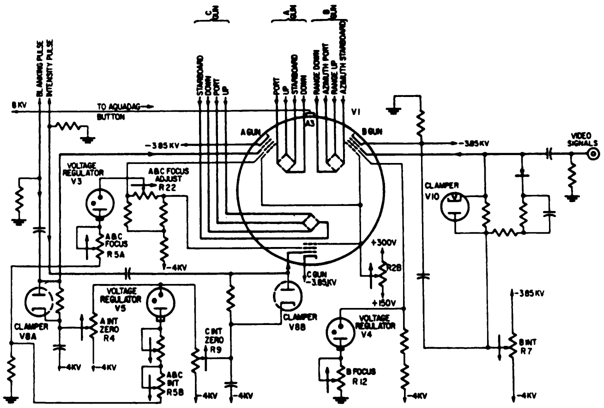
DIRECT VIEW STORAGE TUBE

A direct view storage tube (DVST) is similar in many respects to a conventional CRT, but has some differences which make it superior for an airborne radar display. Among its chief advantages are the following:

1. Higher light output when required.
2. Longer persistence of the display highlights.
3. Persistence controllable for adaptation to a wide variety of conditions (search/track, etc.).
4. Smaller overall package design is possible.

There are many others that could be mentioned, but the above will suffice for the purposes of this discussion. Figure 10-17 shows a DVST as used in the AN/APQ-72 radar in the F-4B aircraft. The entire tube is potted within its magnetic shield to provide protection against mechanical shock, vibration, humidity, and leadkage between bulb terminals.

The major difference between CRT and DVST display devices is the inclusion in the DVST of a low velocity electron gun known as the viewing or flood gun. It is through this viewing gun that the advantages of the DVST can be realized. It is the viewing gun electrons



AQ.182

Figure 10-16. -Multiple gun CRT schematic.

that provide all of the significant light output from the DVST and, since it is the major difference between the DVST and the CRT, a discussion of the viewing gun and its operation will answer most questions about storage devices of this type. (See fig. 10-18.)

The heater/cathode combination performs the usual function of emitting electrons, and the screen provides the conversion of electron energy to light energy, its usual function. The less usual parts or functions (fig. 10-18) are as follows:

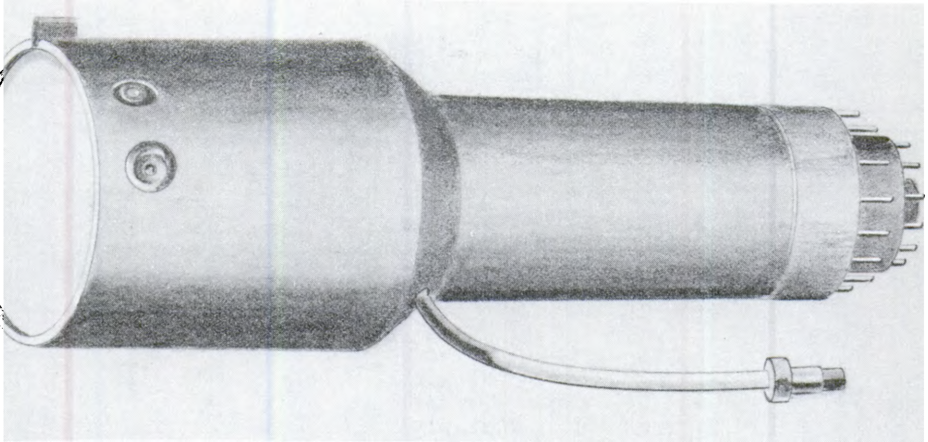
1. Grid No. 1-Viewing grid No. 1 is unusual in that its major function is not signal insertion or the cutting off of electron flow. The negative field between it and the cathode serves only to shape the electron beam.

2. A2-This grid, sometimes known as grid No. 2, also affects the shape of this electron beam and accelerates the beam toward the screen. However, since this element is common to the "writing gun," it also affects the focus (astigmatism) of the writing gun and therefore has a very limited operating range unless the mean potential of the writing gun deflection plates is made adjustable.

3. Collimator-This electrode is in the form of a large cylinder through which the diverging electron stream must pass on its way to the screen. The stream is made to diverge (spread out) by adjustment of the grid No. 1 and A2 voltages. This is what is meant in this case by shaping the electron stream. In theory, the collimator, as its name implies, now attempts to influence this diverging electron stream so as to "make parallel" or collimate these diverging electrons. As can be seen from figure 10-18, this element can be made positive or negative with respect to A2 and therefore can create a positive or negative field to accomplish collimation. In actual practice, it is more important to achieve uniform current density than a parallel beam, and this is done by observing the screen for as nearly uniform illumination as possible while adjusting A2, grid No. 1, and the collimator voltages.

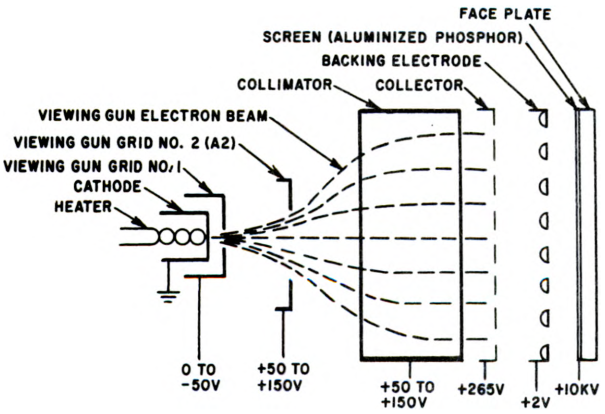
4. The collector is an electrode, which consists of a fine wire mesh, tightly stretched, and provides additional acceleration of the collimated beam. Because the collector is a mesh, about half of these electrons will pass through. The remainder will be collected directly by the collector. It has the additional function of collecting secondary electrons emitted by the backing electrode.

5. The backing electrode performs the storage function for the DVST and is often referred to as the "storage grid." Like the collector, it consists of tightly stretched, fine wire mesh, but additionally the back of this mesh is coated with a material which has the property of emitting, on the average, more than one secondary electron for each primary high velocity electron that strikes it. From figure 10-18, it can be seen that the viewing gun electrons that pass through the collector find themselves in a negative field, the backing electrode being a +2 volts. Since their initial velocity is low (only +265 volts from cathode to collector for acceleration), they approach this backing electrode at almost zero velocity. Under the initial conditions shown in figure 10-18, most of the electrons drift through the mesh



AQ.183

Figure 10-17.—Direct view storage tube.



AQ.184

Figure 10-18.—DVST pictorial diagram.

and are rapidly accelerated by the screen voltage, which can be as high as +10,000 volts.

The viewing gun electrons are now high velocity electrons and, when they strike the phosphor, illuminate the entire screen area (or nearly so if the tube has been previously collimated). If the backing electrode is made negative with respect to the viewing gun cathode, fewer electrons would pass through it, and there would be less light emitted from the screen. If this process is carried on far enough, complete cutoff of light could be accomplished, since all electrons approaching this negative electrode would be turned back to the collector. This can be done by a process called erasing.

A usual value for backing electrode cutoff is about -6 volts, so that any time the side of the backing electrode facing the cathode is between -6 volts and 0, the screen will have some degree of illumination (maximum at 0, minimum at -6 volts). The backing electrode can be considered as a capacitor, with the mesh as one plate and the backing materials as the other. (NOTE: The backing material is a poor conductor or semi-insulator and therefore insulates itself from the mesh while acting as a capacitor plate.)

Equivalent Circuit

The equivalent circuit (fig. 10-19) is a two-dimensional simplified representation of the three-dimensional tube. The electron beam flow is from left to right. The capacitance of the backing electrode is indicated, neglecting the parallel resistance which would indicate the effect of dielectric surface leakage. From figure 10-19, it can be seen that electrons will flow into the left-hand plate of the capacitor until that plate is the same potential as the diode cathode, D1, which is 0 volts in this case. The charge on the capacitor is now 2 volts. Electrons from the viewing gun pass through the backing electrode at a maximum density because the backing electrode is at 0 volts on the viewing gun cathode side.

Consider the results if this capacitor were suddenly switched from a +2-volt source to a +8-volt supply. Since the charge on the capacitor cannot change instantaneously, the left side of the capacitor becomes 6 volts positive and viewing gun electrons flow until the charge on the capacitor is 8 volts. If at that time the capacitor is switched back to the +2-volt supply, the left side of the capacitor will be at -6 volts (total charge still 8 volts)– the viewing gun will be cut off, and the screen is dark. Now if the capacitor is switched back to the +8-volt supply, the screen will be illuminated to maximum brightness; and when it is returned to the +2-volt position, the screen will be dark. If the switching is rapid between +2 and +8 (using a multivibrator for example), the light emitted from the screen will assume some average value between maximum (or saturated) light output and 0, depending on the percentage time spent at +8 volts compared to the PRF (duty cycle).

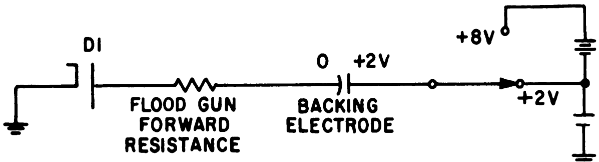


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Figure 10-19.–Equivalent circuit for erasing operation.

Erasing

It can be seen from examination of the equivalent circuit that there is no discharge path for this capacitor or backing electrode other than capacitor leakage. This is so because the viewing gun cathode can supply electrons but cannot take them back, hence the reason for including a diode in the equivalent circuit. In theory then, a storage tube could be made, which, once cut off in this manner, would remain cut off for extremely long periods of time (days). In a practical storage tube, however, this cutoff condition can be maintained for several seconds to several minutes, depending primarily on the quality of the vacuum and the storage grid. The apparent storage time can be increased by a process called overerasing which can be done by adjusting the +8 volt supply or pulse to +10 or +12 volts. But this is not a desirable situation in most cases, since it reduces the sensitivity of the tube considerably. (There may be times when it would be desirable to trade sensitivity for increased storage time, however.

We can also see that, as in the case of any resistor-capacitor combination, a certain amount of time is required to affect the charging of the capacitor. The storage grid time constant is typically 5 milliseconds, and it takes about 10 time constants for complete charging (50 milliseconds) of the storage grid.

This can be accomplished by turning on the +8-volt supply for 50 milliseconds, or it can be done by turning on the +8-volt supply 1 millisecond 50 times or any combination of pulses and pulse widths whose total comes to 50 milliseconds or more.

After this erasure process is completed, the storage grid is ready to accept information to store. This is accomplished by means of a writing gun, identical in every respect to a conventional CRT electron gun. The writing gun supplies a finely focused, high velocity electron stream that can be deflected to any area of the storage grid in the usual manner. Figure 10-20 shows the actual tube construction and the relationship of the writing gun to the viewing gun.

This high velocity electron beam will strike the storage grid and, because of its high velocity, several secondary electrons will be emitted by the storage grid for every primary electron that strikes the grid. These secondary electrons are collected by the collector and the effect is to bring that area of the storage grid out of cutoff. This in turn allows viewing gun electrons to pass through the grid continuously and illuminate the screen. The more primary electrons that arrive, the farther out of cutoff the storage grid will go, up to the point where it tries to become positive with respect to the viewing gun cathode. The presence of viewing gun electrons will prevent the grid from going above cathode potential because, if it did, conduction would bring it back down. Hence it can be seen that a slow scanning, low current density beam will eventually write just as brightly as a high current density, fast scanning beam. In fact, a writing gun which is very nearly cutoff will eventually write to full light output if it is allowed to stay in one spot long enough. Wherever this writing beam hits the storage grid, the grid is moved out of cutoff by some amount, depending on the current density and the dwell time of the beam; also, where the storage grid is above cutoff, viewing gun electrons pass through the grid and continuously illuminate the screen. It is through this continuous illumination that the high light output is

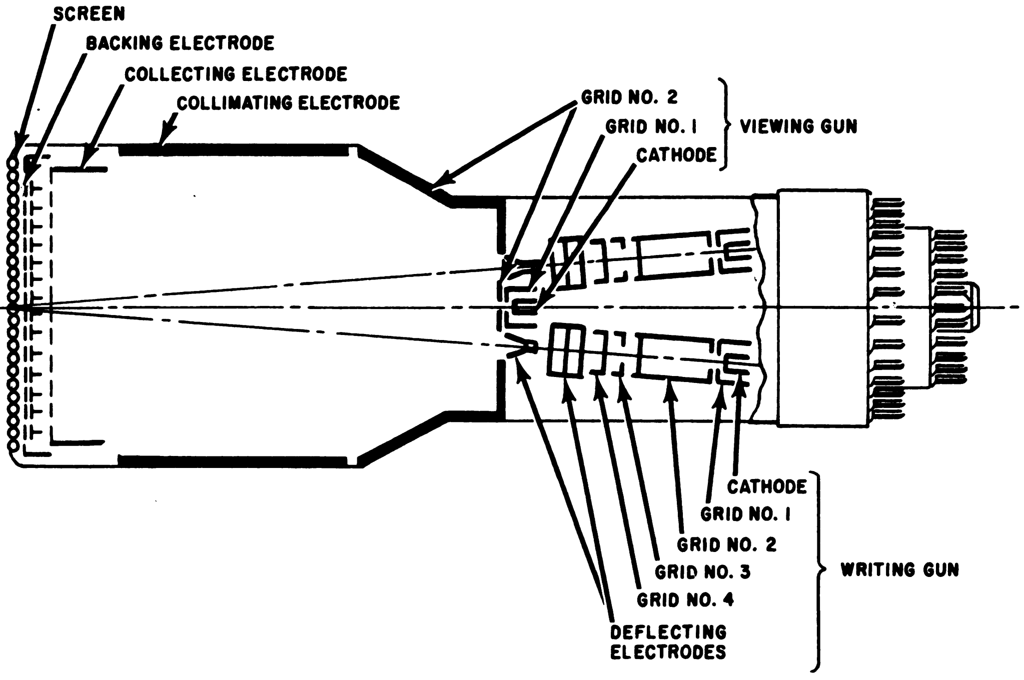

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Figure 10-20. –Cross sectional view of DVST.

obtained. Otherwise, the light output of a storage tube would be about the same as a conventional CRT of similar design. It is this high light output that permits using the display in relatively high ambient light conditions or, if that is not required, permits the use of filters of various types that would attenuate the light of a CRT to otherwise prohibitively low values.

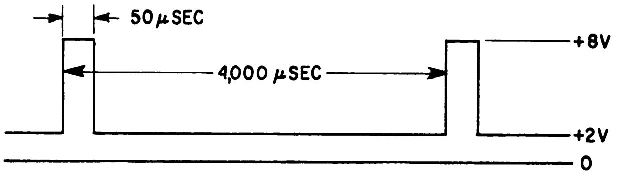

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Figure 10-21. –Erase pulse.

Controllable Persistence

It was mentioned earlier that not only could long persistence of the bright display be obtained but that this persistence was controllable. Let us see how this can be done.

Suppose it is desirable to have approximately 4 seconds persistence. One way in which this could be done would be to "write" for 4 seconds and at the end of that time, apply one 50-millisecond erase pulse. It works, but it is somewhat disconcerting to the operator to receive a burst of full light output every 4 seconds. In addition, the information presented to the operator would not be continuous since at the completion of the single erase pulse the screen would be clean and information would have to be completely rewritten!

A better way would be to supply a chain of erase pulses continuously in such a manner that changing information, being continuously renewed, would decay only slightly between scans of the writing gun. One way to do this is by supplying the waveform to the backing electrode that appears in figure 10-21.

The PRF of this waveform is (1/4000) x 10^6 = 250 pps. Since 50 milliseconds (50 x 10^{-3} seconds) is required to effect complete erasure, the number of pulses required for erasure is (50 x 10^{-3}) ÷ (50 x 10^{-6}) = 1,000 pulses. At 250 pps, 1,000 ÷ 250 or 4 seconds are required to effect complete erasure. Mathematically,

$$\text{Persistence} = \frac{50 \times 10^{-3}}{\text{PRF} \times \text{PW}} = \frac{\text{Total time for erasure}}{\text{Portion of erasure accomplished each erase pulse cycle}}$$

The 50 milliseconds is a tube constant which can be different for different tubes and may even vary slightly within tubes of the same type. But it is typical of many tubes in current production. Persistence can be changed at will by changing either the PRF or the width of the erase pulses or both. The amplitude of the pulse must be carefully adjusted to achieve cutoff without overerasure or undererasure. Overerasure results in severe loss of writing sensitivity since small signals will no longer bring the storage grid out of cutoff. Undererasure will mean old information will never be erased from the display area, resulting in smearing and the loss of dynamic range (ratio of smallest signal to largest signal, usually measured in db).

The means for changing persistence to suit conditions are now available. Hence for fast-changing displays, short persistence is desirable so the PRF may be stepped up to 2,500 pps to achieve a 0.4-second persistence. A control could be supplied so that the persistence can be made continuously variable from very short to very long.

Screen Damage

By its nature, a storage tube screen is harder to damage by misuse than a conventional CRT. However, some precautions and some peculiarities of the tube should be pointed out.

Where damage to CRT screens results in dark spots due to burned phosphor, similar damage to a DVST results in a bright spot since the burn is usually not on the phosphor but on the storage mesh. This has the effect of "shorting" the capacitor in the area of the burned spot, and that area can never be cut off. To avoid such damage, the writing gun should never be allowed to collapse to a spot and remain stationary for a long period of time. Similar treatment to a CRT results in nearly instantaneous screen damage and, though it takes a little longer with a storage tube, damage will be done. Since the intensity of a storage tube is controlled by varying the screen potential (+10 kv), merely turning down the intensity control will not prevent this type of damage since it only controls screen current. The writing gun bias must be turned down to prevent this type of damage to the storage grid.

Another way to damage the DVST is to write on areas not illuminated by the viewing gun since there would be no supply of viewing electrons to prevent charging the storage mesh up to a destructively high voltage. Since the capacitor is "rated" at 35 volts, breakdown would occur when the voltage exceeds some value near its rating. (A sharp-eyed observer will note that as soon as this potential exceeds the collector potential of +265 volts, the secondary electrons will no longer be collected by the collector and further charging toward 2,400 volts would be limited.) Even so, +265 volts would still cause failure.

As was stated earlier, the principal source of light output from the screen is the effect of the viewing gun electrons. Some of the high velocity electrons from the writing guns will pass through to the screen, however, and illuminate it. This illumination is more apparent under some conditions than others (for example, with low screen voltages). The persistence of this "write through" is the same as that built into the phosphor screen and is not controllable. And, because of the geometry of the DVST components, the "write through" may appear slightly displaced from its stored counterpart. Because of its different character (that is, very short persistence, smaller line width, and in most cases lower light output), it is easily distinguished from the stored information and causes little concern unless the operator is not familiar with its cause.

Some of the advantages offered by the DVST may not be so apparent on first examination. Very important is the saving in total weight and size of an indicating system using a DVST.

For example, because the backing electrode is very nearly at ground potential, it forms an effective shield between the writing gun deflection system and the +10,000-volt screen potential. This factor, added to the relatively low writing gun voltage required for proper operation, allows subminiature tubes to be used in the writing gun deflection system. Similar size savings are to be realized in the writing gun power supply.

In addition, because of the characteristics of the backing electrode, it is unnecessary to drive the writing gun grid to zero bias to obtain maximum light output, as in the case with the conventional CRT's. Additional savings in weight, space, and power consumption are to be realized in the design of the video amplifier. Again, subminiature tubes become practical.

As a result, a given indicating system can be packaged so that it is shorter in length, smaller in cross sectional area, and lighter in weight. This requires less primary and secondary power, yet provides target detection enhancement and display brightness that would normally not be possible with conventional CRT devices.

VERTICAL DISPLAY INDICATOR

The vertical display indicator (VDI) discussed in this chapter is the AN/AVA-1 installed in the A-6A aircraft. It is the result of a special study of aircraft instrumentation. The purpose of this study was to develop an integrated display concept that would provide a single optimum cockpit design which would have all of the necessary data displayed in a configuration that would require a minimum of interpretation and coordination on the part of the pilot. This would permit optimum utilization of the weapons systems' capabilities by increasing the speed and precision of pilot response; and it would increase flight safety by decreasing pilot fatigue, tension, and the possibility of vertigo during instrument flights. These features are vitally important in a high-speed, low-level attack aircraft.

The VDI is an analog computer readout device designed to display a three-dimension world picture 50 times per second. The vertical dimension of the display represents ±20° elevation, and its horizontal dimension represents ±25° relative bearing. The third dimension, range, is illusionary; it is created by intensity modulating the display with symbols which are formed and moved in accordance with the rules of perspective.

The readout is traced as a rectangular raster on a CRT. The raster is essentially a conventional TV raster, except that it is swept from the bottom to the top of the display.

The VDI presents to the pilot an easily interpreted televisionlike display all of the flight and command information he must have to fly his complete mission under any weather condition. The symbols it generates, representing a vertical field of ±20° and a lateral field of ±25° (table 10-2), are displayed in perspective and motion to create an analog of the world as viewed through the forward cockpit window. This display is defined as "contact analog."

Symbols, as selected on the control console, are presented against this electronically produced analog of the real world's vertical plane. Commands and flight cues, received from other aircraft systems (fig. 10-22) and presented on this familiar background, are followed almost automatically by the pilot, saving the time formerly required to read and interpret scattered gages, indicators, and displays, and then translate the acquired information into the correct commands to the aircraft.

The VDI, operating in the contact analog mode, presents easily perceived ground and sky texture as a background to flightpath presentation (fig. 10-23), as well as other visual and instrument flight cues which also assist the pilot under both visual and instrument flight conditions. The relative size and position of the display elements are automatically adjusted by variable signals originating in sensor equipments and processed in the Ballistics Computer Set AN/ASQ-61. (The DIANE computer AN/ASQ-61 is described in chapter 11.) A transparent command flightpath is superimposed on the ground and sky textures. This command flightpath consists of a centerline, command heading lines which converge at the horizon, and horizontal tar strips. The command flightpath geometry is continuously altered to present heading, attitude, altitude, and attack command signals. The horizontal tar strips in the flightpath appear to move toward the pilot, creating the proper impression of speed. The direction of motion and speed of the command speed markers at the right of the flightpath relate the actual airspeed to the command airspeed. Movement of the command speed markers toward the pilot indicates that the aircraft is exceeding the command speed, while movement of the command speed markers away from the pilot indicates that the aircraft is below the command speed.

When the aircraft is above the prescribed flightpath, the flightpath on the VDI narrows; while if the aircraft is below the prescribed altitude, the path appears extra wide. Deviation from the command course is presented as a lateral distortion of the displaced flightpath.

A simulated horizon line separates the sky and ground textures and moves up or down in relation to fixed fiducial markers at the edge of the display to indicate aircraft attitude. To

Table 10-2.—Vertical display symbols and markers.

Symbol designation	Description	Gray scale	Max. dim.	Min. dim.	Max. display angular range	
					Hor.	Vert.
GROUND TEXTURE ELEMENTS	Elliptical elements that emanate from the horizon and move in accordance with a quasi-random ground plane.	Dark gray	Major axis 1.5 in.	Major axis 0.5 in.		±20°
PERSPECTIVE GRAY SHADING	The ground texture is backed by a perspective shading which varies from black at horizon to light gray at display bottom.	Black to light gray				
SKY	Analog of sky.	Medium to light gray				
CLOUDS	Analogs of cumulus clouds: stationary for fixed A/C attitude—move with attitude change.	Light gray	Major axis 1.5 in.	Major axis 0.5 in.		±20°
FLIGHTPATH	Vertical lines converging at the horizon.	Black	50° real world	25° real world	±25°	±10°
TAR STRIPS	Horizontal lines that move down the path, sized and spaced in perspective.	Dark gray	0.25 in. wide	0.125 in. wide		±20°
IMPACT POINT	A solid circle used to indicate the impact point of A/C.	Bright	5/32-in. circle fixed		±25°	±20°
COMMAND SPEED SYMBOL	Three parallelograms that are placed in a line and paralleled to path.	Bright	0.375 in. long 0.25 in. wide fixed			
COMMAND HEADING LINES	Three lines that radiate from the path apex and rotate with heading error.	Dark gray	0.06-in. wide fixed			

Table 10-2.—Vertical display symbols and markers—Continued.

Symbol designation	Description	Gray scale	Max. dim.	Min. dim.	Max. display angular range	
					Hor.	Vert.
±30° PITCH LINE	These lines denote ±30° elevation angles when in display center.	Black Black	0.125 in. wide 0.125 in. wide fixed			±20° ±20°
+60° PITCH LINE	Same function as above.	Black	0.25 in. wide fixed			±20°
+90° PITCH LINE (ZENITH MARKER)	A dashed line with six segments; same function as above.	Black	0.25 in. wide fixed			±20°
PULLUP MARKER	A line that moves down the path in perspective and denotes pullup when at bottom of display.	Black	0.25 in. wide	0.06-in. wide		±20°
RELEASE MARKER	A horizontally elongated "L" that moves down the path in perspective.	Black	0.25-in. hor. 0.75-in. vert.	0.06-in. hor. 0.37-in. vert.		±20°
TARGET SYMBOL	A solid square that indicates the position of the target in the ground plane.	Bright	0.25-in. square fixed			±20°
WEAPON SYMBOL	A hollow square that denotes weapon on target when circumscribing target symbol.	Bright	0.625-in. square 0.125 in. line width fixed			±25°

enhance the illusion of a true world picture, the display is darkened at the horizon and gradually increases in brightness toward the foreground. When the aircraft angle of attack exceeds ±20°, the horizon line no longer appears on the display, and the distinctive pitch lines which indicate ±30°, +60° and +90° pitch are generated.

The entire display is rotated mechanically to provide the pilot with realistic roll information (fig. 10-24). All connection to the deflection yoke are by sliprings to permit the roll servo to rotate the yoke in excess of 360°. All command and orientation indications other than null indications are qualitative only; e.g., the horizon does not represent any specific distance, a target symbol placement does not indicate any specific range or bearing.

The VDI automatically shifts to the attack phase at the command of the DIANE computer. The target symbol appears on the display when it is in range. The pilot maneuvers the aircraft to center the target symbol inside the weapon symbol on the flightpath. (See fig. 10-25.) The correct release point, dependent on the weapon selected, mode of delivery, and aircraft parameters (e.g., load, altitude, speed, and escape time), is computed by the DIANE. This information is presented on the VDI as a release marker which originates at the display center and moves down the flightpath. The weapon is

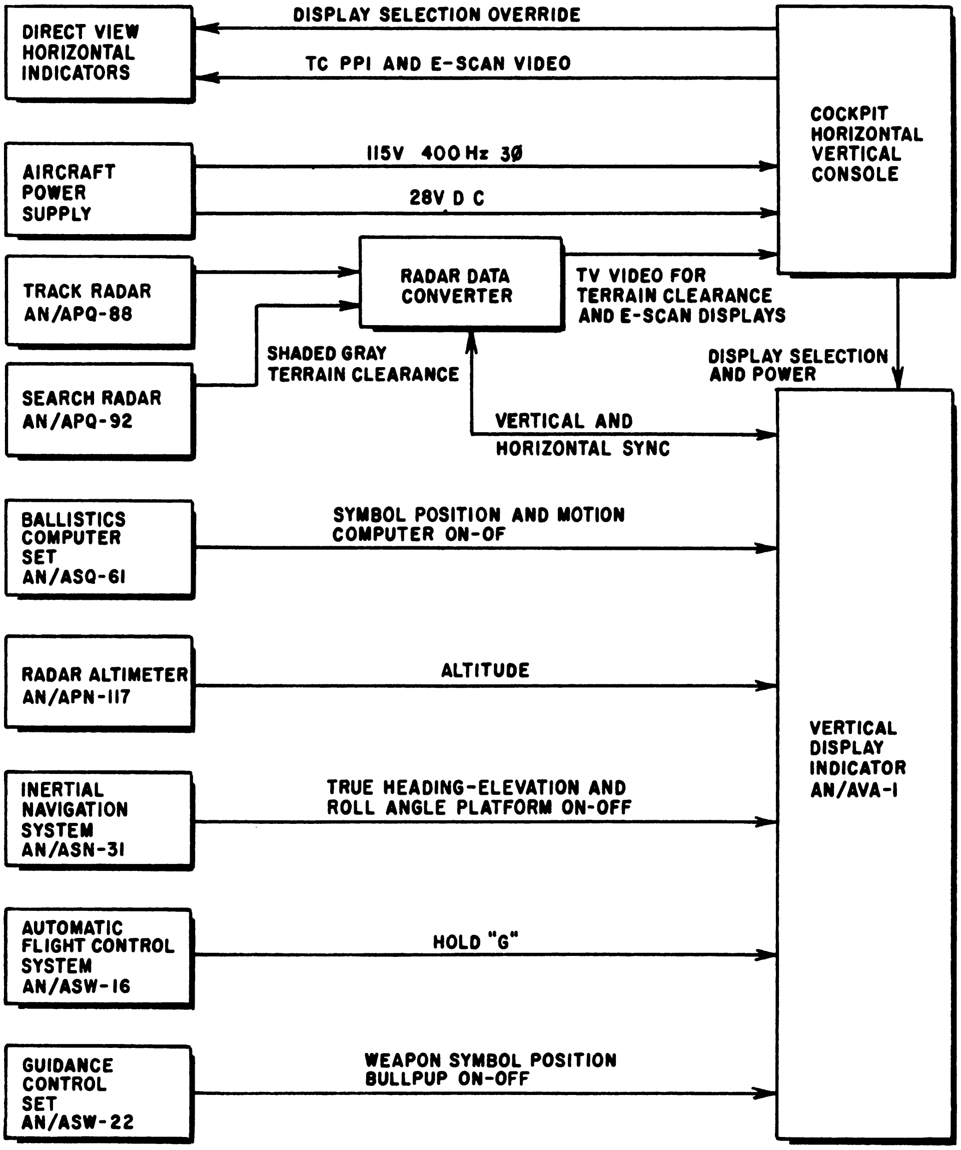
DIRECT VIEW HORIZONTAL INDICATORS
DISPLAY SELECTION OVERRIDE
TC PPI AND E-SCAN VIDEO
COCKPIT HORIZONTAL VERTICAL CONSOLE
AIRCRAFT POWER SUPPLY
115V 400 Hz 3Ø
28V D C
TRACK RADAR AN/APQ-88
RADAR DATA CONVERTER
TV VIDEO FOR TERRAIN CLEARANCE AND E-SCAN DISPLAYS
SHADED GRAY TERRAIN CLEARANCE
DISPLAY SELECTION AND POWER
SEARCH RADAR AN/APQ-92
VERTICAL AND HORIZONTAL SYNC
BALLISTICS COMPUTER SET AN/ASQ-61
SYMBOL POSITION AND MOTION COMPUTER ON-OF
RADAR ALTIMETER AN/APN-117
ALTITUDE
VERTICAL DISPLAY INDICATOR AN/AVA-1
INERTIAL NAVIGATION SYSTEM AN/ASN-31
TRUE HEADING-ELEVATION AND ROLL ANGLE PLATFORM ON-OFF
AUTOMATIC FLIGHT CONTROL SYSTEM AN/ASW-16
HOLD "G"
GUIDANCE CONTROL SET AN/ASW-22
WEAPON SYMBOL POSITION BULLPUP ON-OFF

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Figure 10-22. -VDI subsystem interconnection block diagram.

released when the marker hits the bottom of the display.

In addition to the primary contact analog mode of operation, the pilot can select two alternative modes: terrain clearance or E-scan as described in chapter 9 of this manual. The command flightpath, but not the ground and sky texture, is displayed along with processed video from the search radar. (See fig. 10-26.) High points, i.e., points at or above the selected altitude, are indicated as bright returns; low points, as shadows. E-scan is intended primarily as a secondary mode in case of failure of the search radar or terrain clearance. It is obtained by processing returns from the attack radar operating in its secondary mode. The E-scan display contains processed radar information only; it shows the depression angle and the true range to ground targets along the aircraft line of flight.

Symbol Circuits

The symbol circuit (fig. 10-27) must perform two major functions: First, it must generate its distinctive symbol; and second, this

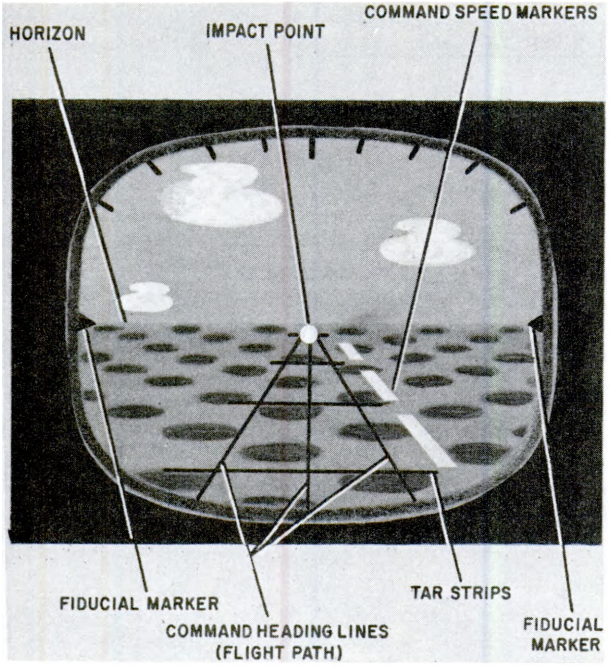

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Figure 10-23. –VDI display–A-6 in level flight on command path.

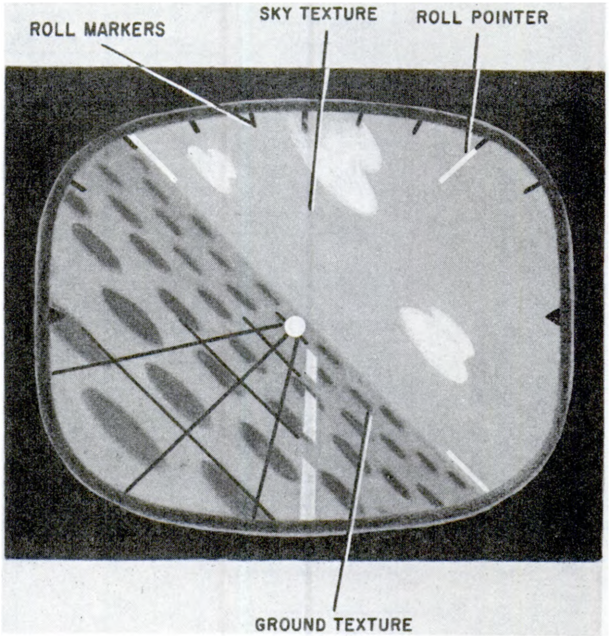

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Figure 10-24. –Aircraft at 45° left roll.

symbol must be located. In addition, the symbol must be dimensioned on the display in accordance with the rules of perspective. Dynamic changes in both size and position must be controlled automatically.

Since the horizontal and vertical driving voltages are linear, any location of the face of the scope can be given in terms of horizontal and vertical deflection voltages from the center (Ov, Ov); 1-inch deflection, horizontal or vertical, equals 8.57 volts.

The horizontal sweep sawtooth is summed with a d-c reference level signal supplied by the DIANE computer (or other sensing equipment) to the horizontal variable delay pickoff. The pickoff acts as a switch which is open until a fixed voltage is applied and closed after it is applied. The pickoff output, a ramp voltage, is applied to a differentiator circuit giving an output pulse width equal to the duration of the ramp input. The pulse is then differentiated to give a positive impulse at the leading edge and a negative impulse at the trailing edge.

The positive impulse triggers a blocking oscillator (single cycle, 9.6 μsec). The sine wave is amplified, and then clipped to form a square wave of 9.6 microseconds duration.

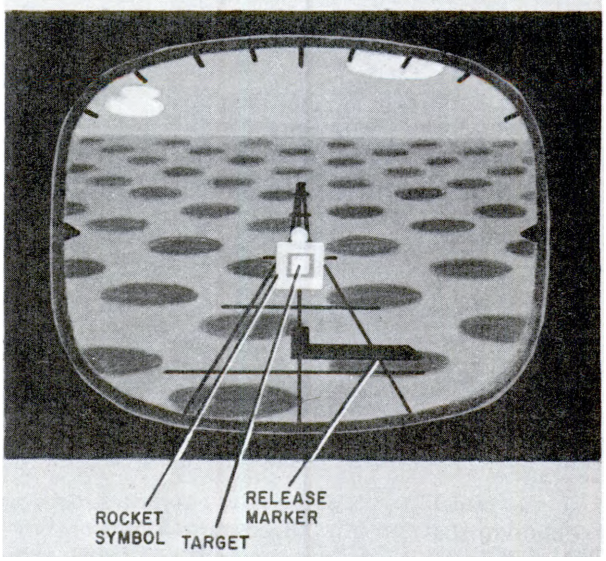

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Figure 10-25. –Pitch and heading errors zeroed prior to weapon release.

The square wave is then integrated and amplified to form a back-to-back sawtooth, which is fed through a clipper, and the clipping level adjusted by the vertical sawtooth. The clamped back-to-back sawtooth is then fed to a saturating amplifier chain to form a positive horizontal gating pulse to the coincidence gate.

The vertical gating signal is generated in the same manner. The input signals are the vertical sawtooth and a d-c positioning signal. The blocking oscillator period is 2.86 milliseconds.

There is a positive output signal to the video mixer and amplifier only when both the vertical and horizontal gating pulses are applied to the coincidence gate. This symbol may be placed anywhere on the display by varying the reference potentials applied to the horizontal and vertical variable delay pickoffs.

Three operations are performed on a symbol to create the impression of motion in three dimensional space. As it approaches the display foreground, the symbol is affected as follows:

1. Amplitude (intensity) is increased.
2. Size is increased.
3. Speed is increased.

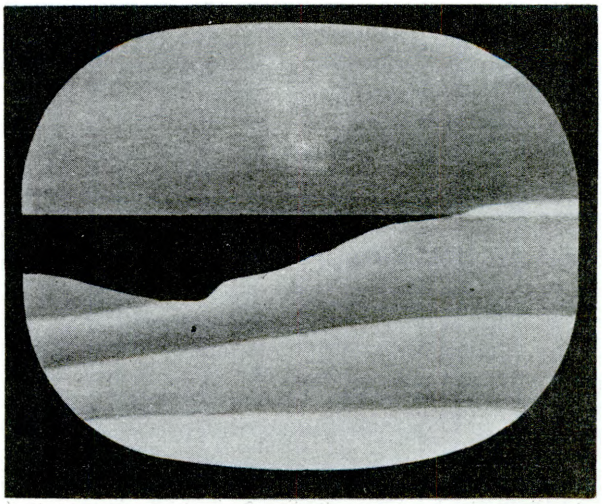

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Figure 10-26.–Vertical display indicator: terrain clearance mode.

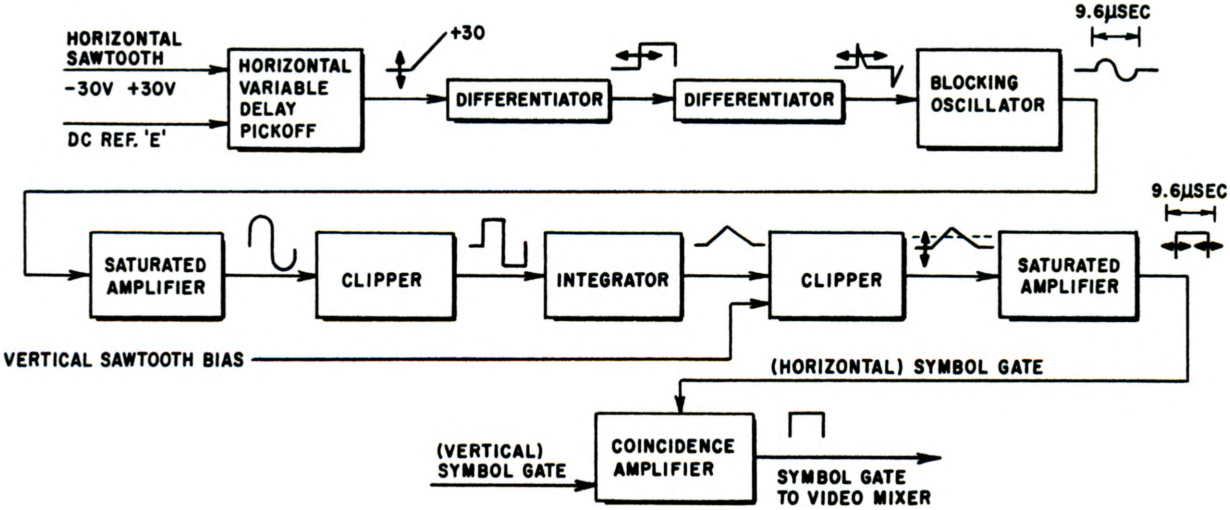

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Figure 10-27.–Sample signal generator block diagram.

Operation one is performed on all video to enhance the illusion of distance in the display. A portion of the vertical sweep voltage is applied as bias to the video amplifier during the ground display section only. Since the sky texture remains stationary in straight and level flight and is not proportioned to represent distance, it is not affected by the horizon shading circuits.

Motion inputs (input voltage level variations) are used to simulate motion relative to the aircraft. Except for the target symbol, size variations are employed to represent changing distance between the aircraft and the item being represented by the symbol.

Operation and Controls

The pilot selects and controls the desired displays on both the VDI and the pilot's horizontal display on the Cockpit Horizontal-Vertical Console. These controls are illustrated in figure 10-28. Although the pilot can arbitrarily select any display mode on the console, the bombardier/navigator must operate the search or track radar in the proper mode to supply the correct radar information.

Power Supplies

The low voltage power supply is an a-c to d-c converter which supplies properly filtered d-c power for the VDI transistor circuitry. The high voltage power supply converts aircraft power of 115 volts, 400 Hz, to 10,000 volts d. c., and 500 volts d. c. to operate the cathode ray tube.

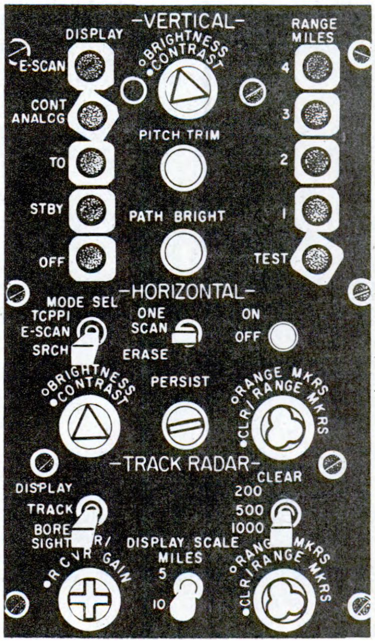

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Figure 10-28. –Cockpit Horizontal-Vertical Console.

CHAPTER 11

DIGITAL COMPUTERS

Present and future technicians will be faced with a collection of electronic equipments which use computers as integral portions of the overall system. To understand the operation of the system in general, and the computer portion in particular, it is necessary to have a basic understanding of computer functions, circuitry, terminology, and applications. Basic Electronics, NavPers 10087-B, chapter 16, presents a basic coverage of the purpose, operation, and theory of computers, together with some of the terminology peculiar to them. Review and study of these basic coverages will aid in understanding the material covered in this chapter.

INTRODUCTION TO DIGITAL COMPUTERS

In the past few years, the term digital computer has appeared in Navy nomenclature. This term refers to an electromechanical device which is used in applications such as fire control, communications, and tactical data processing. Digital computers accomplish things that were impossible before, and they speed up processes which formerly required considerable time. Although the operations of computers are not new, the techniques of electronics have made possible a computer contained in a small, lightweight package which is adaptable to aircraft systems. Also, prior to the incorporation of electronics in digital computers, the great speed of operation required was impossible with purely mechanical devices.

The technician of today is faced with equipments which have the computer used as an integral part of the overall system. Therefore, the technician must have a basic understanding of computer functions, the circuitry involved, the numbering system used, and computer terminology.

The definition of a computer is: Any device capable of accepting information, applying mathematical operations to that information, and obtaining useful results of these operations. Therefore, a computer must have an input, processing, and output section.

Before any problem can be solved by a computer, the quantities involved must be expressed in terms of common units; that is, digital computation is the process in which digits alone are used to solve the problem.

Basically, the purpose of a digital computer is the same as that of any other computational aid. However, it is more accurate within practical limits of speed. Computers can perform thousands of repetitive computations involving hundreds of thousands of digits without making an error. Further, they can store millions of items of information for future use.

Digital computers also have limitations in that a continuous variable cannot be processed. Simple and explicit instructions (programing) must be provided for each operation that is to be performed. Instructions as to where information is stored, how to use it, what to do with it, and what step is required next are sometimes more complicated than the problems the computer is used to solve. Approximations and rounding off are also problems encountered with computers.

A digital computer performs its calculations by counting and comparing. With this simple capability, it can add, subtract, multiply, divide, and make logical decisions. Therefore, to perform computations with a digital computer, all that is needed is the provision of a method which will enable the machine to count, compare, and transfer a digit from one place to another. Therefore, before a discussion of computer devices, it is necessary to learn the language of the computers.

NUMBERING SYSTEMS

While there are many different numbering systems, this discussion will deal with only two; that is, the base ten (decimal) and base two (binary) systems. The binary system will be compared with the decimal system because most computers utilize the binary system and most readers understand the decimal system. The bistable nature of simple electronic components such as switches (open or closed) and tubes and transistors (conducting or cutoff) makes the binary numbering system quite usable.

In the decimal system there are ten digits used (0 through 9), and in the binary system there are two digits used (0 and 1). The symbols or digits used are repeated as many times as desired or needed. Both systems also use the place value of positional notation concept. This means that a numeral has a specific value by virtue of its position.

An example of place value is shown in the two numbers 230 and 203. The 3 has a different value in each numeral by virtue of its position.

POSITIONAL NOTATION

In the previous example the numeral 230 when stated by the reader to be two hundred thirty, some assumptions are made which must be understood in order to compare the decimal and binary systems.

The first assumption the reader made was that when the number 230 was first looked upon, the number was assumed to be a decimal number. When no base symbol is given, the decimal system is assumed. If the number had been a base four number, it would have been written as $230_{(4)}$ with the 4 indicating the base of the numbering system. Some examples and their numbering base symbols are as follows:

Number	Base
398	ten (decimal)
$342_{(5)}$	five (quinary)
$101_{(2)}$	two (binary)

Therefore, when a number is written in base ten, no base indicator is given. If the number is written in a base other than ten, the base indicator is used.

Another assumption made is that the number 230 is two hundred thirty; that is, the digit 2 indicates hundreds, the digit 3 indicates tens, and the digit 0 indicates units. In base ten, this is true. The digits have specific values according to their position. Place value or positional notation for the number 378924 in the decimal system is as follows:

Place value	10^5	10^4	10^3	10^2	10^1	10^0
	100000	10000	1000	100	10	1
number	3	7	8	9	2	4

Notice that the place value column on the right is 10^0 or 1. The increasing place values, moving to the left, are indicated by the base (10) raised to one greater power. The second place value column is, then, 10^1, the third is 10^2, etc.

The number 378924, then, is 3(100000) + 7(10000) + 8(1000) + 9(100) + 2(10) + 4(1).

The place value columns for the binary (base two) system follow the same pattern as the base ten system except the base two is used.

For example, the number $10110_{(2)}$ is indicated in the place value chart for base two as follows:

Place value	2^4	2^3	2^2	2^1	2^0
	16	8	4	2	1
Number	1	0	1	1	0

The number $10110_{(2)}$, then, is $1(16) + 0(8) + 1(4) + 1(2) + 0(1) = 22_{(10)}$

Notice that place value in base two has a different value than the same place in base ten.

COUNTING IN BASE TWO AND BASE TEN

In base ten, when counting from 0, the numbers are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9.

The next number to be counted is ten, but there is no single symbol in base ten to indicate the next number. Therefore, a combination of symbols is used by repeating the 0 and indicating a 1 in the tens column. This means one group of tens and no groups of units.

When counting in base two, there are only two digits or symbols; that is, 1 and 0. The same mechanical process is used in base two that was used in base ten. Starting with 0, in base two, the count is 0, 1.

There are no other symbols to indicate the next number so a 1 is written in the next place value column to the left and a 0 is written in the first place value column; that is, 0, 1, $10_{(2)}$.

This last number, then, indicates one group of two and no groups of units. The next number is $11_{(2)}$ which means one group of twos and one group of units. A number such as $1101_{(2)}$ would indicate one group of eights, one group of fours, no group of twos, and one group of units, and in this case is the same as decimal number 13.

Counting comparisons between the decimal and binary systems are made as follows:

Decimal	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000
17	10001

Notice that when counting objects, the decimal 17 and binary 10001 refer to the same object; therefore, decimal 17 must be equivalent to binary 10001.

CONVERSIONS

If the binary number 101 is to be converted to a decimal number, the binary number is written in expanded notation; that is

$$101_{(2)} = 1(4) + 0(2) + 1(1)$$

and the indicated multiplication, by terms, is carried out and yields

$$4 + 0 + 1 = 5$$

The 5 is a base ten number; that is, if objects were counted in a row and stopped with the decimal 5 and then the same objects were counted again in binary, the same object would be indicated with one-zero-one ($101_{(2)}$).

Example: Convert $11101_{(2)}$ to base ten.

Solution: Write $11101_{(2)}$ in expanded notation as

$$1(16) + 1(8) + 1(4) + 0(2) + 1(1)$$

and carry out the multiplication to obtain

$$16 + 8 + 4 + 0 + 1 = 29$$

Problems: Convert the following binary numbers to base ten.

1. 111
2. 1001
3. 11111
4. 1000001

Answers:

1. 7
2. 9
3. 31
4. 65

To convert the decimal number 26 to binary, first intuitively determine the largest place value column contained in the number; that is, in the place value chart

2^5	2^4	2^3	2^2	2^1	2^0
32	16	8	4	2	1

there is one group of 16 or 2^4 in 26. Also, there must be five digits in the representation of 26 in binary because the place value column for 2^4 is the fifth place value column from the right. This is indicated by drawing lines for each digit as follows:

2^4	2^3	2^2	2^1	2^0
-	-	-	-	-

There is one group of 16 in 26; therefore, write

2^4	2^3	2^2	2^1	2^0
1	-	-	-	-

Sixteen is indicated, leaving 26 - 16 to be accounted for, or ten. There is one group of 2^3 in ten so write

2^4	2^3	2^2	2^1	2^0
1	1	_	_	_

After accounting for one group of 16 and one group of 8, 2 is left. There are no groups of 2^2 in 2 so write

2^4	2^3	2^2	2^1	2^0
1	1	0	_	_

and then find there is one group of 2^1 in 2 and write

2^4	2^3	2^2	2^1	2^0
1	1	0	1	_

leaving 0. Finally there is no group of 2^0 in 0 so write

2^4	2^3	2^2	2^1	2^0
1	1	0	1	0

Therefore, 26 in decimal is equal to 11010 in binary.

This type conversion is quite complicated in dealing with large numbers. There is a technique which enables us to convert from decimal to binary quite simply by continual division of the decimal number by the base of the binary system, indicating the remainder after each division operation until the quotient is zero. This is shown in the following:

Convert 26 decimal to binary–

2 |26
13 remainder is 0

2 |13
6 remainder is 1

2 |6
3 remainder is 0

2 |3
1 remainder is 1

2 |1
0 remainder is 1

The remainders are read from the bottom to the top to obtain the binary equivalent of the decimal number; that is,

$$26 = 11010_{(2)}$$

The division process may be combined as follows:

Convert 38 to binary–

2 /38
2 /19 0
2 /9 1
2 /4 1
2 /2 0
2 /1 0
0 1

and the binary equivalent of 38 is $100110_{(2)}$.

Problems: Convert the following decimal numbers to binary.

1. 29
2. 624

Answers

1. 11101
2. 1001110000

BINARY ARITHMETIC

Familiarity with the basic arithmetic operations in the binary system is needed in order to enhance the understanding of computers; therefore, a comparison between the decimal and binary systems will be discussed.

Addition

When counting in the decimal system, a limit is reached where the next number cannot be indicated in a single column; that is,

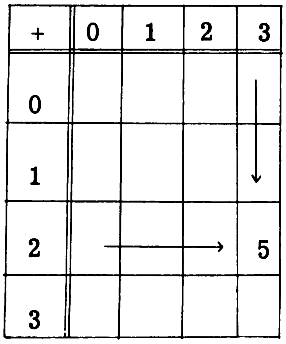
0
1
2
3
4
5
6
7
8
9

At this point a "carry" is made; that is, the first digit (0) is repeated and a 1 is indicated in the tens column. This means one group of tens and no groups of units, and is indicated by 10.

The ADDITION facts of the DECIMAL system are shown in the truth table below:

+	0	1	2	3	. . .
0	0	1	2	3	. . .
1	1	2	3	4	. . .
2	2	3	4	5	. . .
3	⋮	⋮	⋮	⋮	

For example:



means

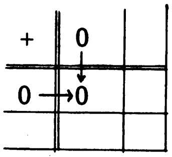
2 + 3 = 5

Binary addition is similar to decimal addition, except in binary only two digits, 0 and 1, are available. The mechanical procedure is the same.

The ADDITION facts of the BINARY system are as follows:

+	0	1
0	0	1
1	1	10

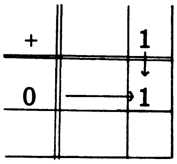
That is,



means

0 + 0 = 0

and



means

0 + 1 = 1

or

1 + 0 = 1

and

+	0	
1	1	

means

1 + 0 = 1

or

0 + 1 = 1

and

+		1
1		10

means

1 + 1 = 10

This means that

0 + 0 = 0
0 + 1 = 1
1 + 0 = 1
1 + 1 = 10

When adding numbers in base ten, the following mechanical procedure is followed:

Add 172 and 32

172	
+ 32	
104	partial sum
+100	carry overs
204	final sum

When adding two binary numbers, the process is

0101	
+ 0111	
0010	partial sum
+ 1010	carry overs
1000	partial sum
+ 0100	carry overs
1100	final sum

The previous addition may be stated as follows:
Starting from the right column, one plus one equals 0 and 1 carry. The carry plus zero plus one equals zero and one carry. The carry plus one plus one equals one and one carry. The carry plus zero plus zero equals one.

Problems: Add the following binary numbers.

1. 1001 and 101
2. 1101 and 1111

Answers:

1. 1110
2. 11100

Computer Addition

The computer technique of addition utilizes the process of half add, carry, and final sum. Half add means to add two digits and neglect the carry. The carry is written below the half add sum and then added to this half add sum. An example in decimal is as follows:

Add 3562 and 2149

3562	
+ 2149	
5601	half add
+ 0110	carry overs
5711	final sum

If other carry overs are required, they are handled as follows:

Add 4965 and 5247

4965	
+ 5247	
9102	half add
+ 1110	carry overs
0212	half add
+ 10000	carry overs
10212	final sum

Problem: Add the following, indicating half adds and final sums.

1. 9328 and 6973
2. 9323 and 739

Answers:

1. 5291 half add
   16201 half add
   16301 final sum

2. 9052 half add
   0062 half add
   10062 final sum

The computer technique is used in binary as it is used in decimal.

Example: Add the binary numbers 11101 and 1101.

Solution:

$$\begin{array}{rl} 11101 & \\ +\ 1101 & \\ \hline 10000 & \text{half add} \\ +\ 11010 & \text{carry overs} \\ \hline 01010 & \text{half add} \\ +\ 100000 & \text{carry overs} \\ \hline 101010 & \text{final sum} \end{array}$$

Example: Add the binary numbers 1101 and 110.

Solution:

$$\begin{array}{rl} 1101 & \\ +\ 110 & \\ \hline 1011 & \text{half add} \\ +\ 1000 & \text{carry over} \\ \hline 0011 & \text{half add} \\ +\ 10000 & \text{carry over} \\ \hline 10011 & \text{final sum} \end{array}$$

Problems: Add the following binary numbers indicating half adds and final sums.

1. 110 and 10
2. 11011 and 111

Answers:

1. 100 half add
   000 half add
   1000 final
2. 11100 half add
   11010 half add
   10010 half add
   00010 half add

   100010 final sum

Subtraction

Both the direct and complement method of subtraction will be discussed. The methods will also be compared in the decimal and binary systems.

DIRECT SUBTRACTION.–In the decimal system, when subtractions are made, the terms to be subtracted are named as follows:

$$\begin{array}{rl} 7 & \text{minuend} \\ -\ 2 & \text{subtrahend} \\ \hline 5 & \text{difference} \end{array}$$

In cases where the subtrahend, in a particular column, is greater than the minuend, a borrow must be made; that is, a digit must be moved from a higher place value column to a lower place value column. An example is

$$\begin{array}{r} 76 \\ -\ 39 \\ \hline \end{array}$$

where 9 is to be subtracted from 6.

In this case one group of tens must be borrowed from the 7 group of tens. This is shown by

$$\begin{array}{r} 76 \\ -\ 39 \\ \hline \end{array}$$

is

$$\begin{array}{rr} & 10 \\ 6 & 6 \\ -\ 3 & 9 \\ \hline \end{array}$$

and 9 from 16 is 7. Therefore,

$$\begin{array}{rr} 6 & 16 \\ -\ 3 & 9 \\ \hline \multicolumn{2}{c}{37} \end{array}$$

This concept may be applied to as many columns as necessary. For example, in the problem

$$\begin{array}{r} 9326 \\ -\ 7438 \\ \hline \end{array}$$

one group of tens is borrowed from the two groups to give

$$\begin{array}{rr} & 10 \\ 931 & 6 \\ -\ 743 & 8 \\ \hline & 8 \end{array}$$

then one group of hundreds is borrowed from the three groups to give

$$\begin{array}{rrr} & 10 & 10 \\ 92 & 1 & 6 \\ -\ 74 & 3 & 8 \\ \hline & 8 & 8 \end{array}$$

The next step is

$$\begin{array}{rrrrr} & & 10 & 10 & 10\\ & 8 & 2 & 1 & 6\\ - & 7 & 4 & 3 & 8\\ \hline & & 8 & 8 & 8\end{array}$$

and finally

$$\begin{array}{rrrrr} & & 10 & 10 & 10\\ & 8 & 2 & 1 & 6\\ - & 7 & 4 & 3 & 8\\ \hline & 1 & 8 & 8 & 8\end{array}$$

The subtraction problem difference may be verified by adding the difference to the subtrahend to give the minuend. This shown by

$$\begin{array}{rr} & 1888\\ + & 7438\\ \hline & 9326\end{array}$$

Binary subtraction problems are solved in the same manner as decimal subtraction problems except base two is used. One fact may cause problems; that is, when 1 is subtracted from 0, the difference is 1 if a borrow of 1 is made. An example of this is shown by the following:

$$\begin{array}{rr} & 10\\ - & 1\\ \hline\end{array}$$

A borrow of 1 is made, to give

$$\begin{array}{rrr} & & 10\\ & 0 & 0\\ - & & 1\\ \hline\end{array}$$

10 (which must be read as "one-zero", and not as "ten") in base two is really 2 in decimal, and 1 from 2 is 1. Therefore,

$$\begin{array}{rrr} & & 10\\ & 0 & 0\\ - & & 1\\ \hline & & 1\end{array}$$

When no 1 is available in the next higher place value column, a higher place value column must be used. This is shown in the following example of binary subtraction:

$$\begin{array}{rr} & 100\\ - & 1\\ \hline\end{array}$$

A borrow from the 2^2 column is made, giving 10 in the 2^1 column.

$$\begin{array}{rrrr} & & 10 & \\ & 0 & 0 & 0\\ - & & & 1\\ \hline\end{array}$$

Then, a borrow of 1 is made from the 10 in the 2^1 column, leaving 1 in this column and giving a 10 in the 2^0 column, and 10 minus 1 is 1,

$$\begin{array}{rrrr} & & & 10\\ & 0 & 1 & 0\\ - & & & 1\\ \hline\end{array}$$

Therefore,

$$\begin{array}{rrrrl} & & & 10 & \\ & 0 & 1 & 0 & \text{minuend}\\ - & & & 1 & \text{subtrahend}\\ \hline & 0 & 1 & 1 & \text{difference}\end{array}$$

Verification of this difference is made by adding the subtrahend to the difference to yield the minuend.

$$\begin{array}{rr} & 011\\ + & 1\\ \hline & 100\end{array}$$

Problems: Find the difference in the following binary subtraction problems.

1. $\begin{array}{rr} & 101\\ - & 10\\ \hline\end{array}$

2. $\begin{array}{rr} & 10101\\ - & 111\\ \hline\end{array}$

Answers:

1. 11
2. 1110

SUBTRACTION BY COMPLEMENTS (BASE TEN). –Digital computers are generally usable to perform subtraction in the manner previously discussed because the process of borrowing involves operations which are impractical to incorporate into a machine. The process which involves complements is used in digital computers. By complement, it is meant the number or quantity required to fill or complete something. The complement of a number is, therefore, another number which completes the original number with respect to a known reference.

For example, the nines complement of a number is that number when added to the original number that will yield all nines in the place value columns used. An example of this is as follows:

What is the nines complement of 32?

What number, when added to 32, will produce 99?

Intuitively, it can be seen that the number is

$$99 - 32$$

or

$$67$$

If one is now added to the nines complement, the tens complement results; that is,

$$67 + 1 = 68$$

and 68 is the tens complement of 32. Notice that if 68 is added to 32, the sum is 100. Therefore, the tens complement of a number is defined as that number which, when added to the original number, yields a 1 in the next higher place value column and zeros in all other columns. The tens complement of 78 is

$$100 - 78 = 22$$

Notice that the tens complement is in reference to a power of ten one place value higher than the highest place value of the original number.

Number	Tens complement	Reference
7	3	10^1
21	79	10^2
309	691	10^3

Rather than subtract the subtrahend from the minuend, the tens complement of the subtrahend (found with reference to the power of ten one place value higher than either the subtrahend or minuend) may be added to the minuend and then decrease this sum by the reference power of ten used to obtain the difference. A step-by-step process is shown to explain the preceding statement.

Example: Subtract 26 from 49

Solution: Write

$$\begin{array}{r} 49 \\ -\ \underline{26} \end{array}$$

then find the tens complement of 26 which is

$$100 - 26 = 74$$

This may be rearranged as follows:

$$100 - 74 = 26$$

Now, instead of writing

$$49 - 26$$

write

$$\begin{aligned} & 49 - (100 - 74) \\ = {} & 49 - 100 + 74 \\ = {} & 49 + 74 - 100 \\ = {} & 23 \end{aligned}$$

This indicates that the minuend (49) plus the tens complement of 26 (that is, 74) are added, then the reference power of ten used (100) is subtracted to give the difference which is 23. Notice that

$$\begin{aligned} & 49 - 26 \\ = {} & 49 + 74 - 100 \\ = {} & 123 - 100 \\ = {} & 23 \end{aligned}$$

the digit (1) found in the place value column higher than the highest place value column of the subtrahend had only to be dropped. Generally, this digit (1) which is developed indicates the difference (23) is a positive value.

Example: Subtract 36 from 429

Solution: Write

$$\begin{array}{rl} 429 & \text{minuend} \\ -\ \underline{36} & \text{subtrahend} \end{array}$$

then

$$\begin{array}{rrl} & 429 & \text{minuend} \\ + & \underline{964} & \text{tens complement of subtrahend} \\ 1 & 393 & \\ = + & 393 & \text{remainder} \end{array}$$

The process of subtracting a larger number from a smaller number, using the tens complement, is slightly different from the example previously shown. Instead of developing a 1 in the higher place value column, a zero will be present. The complement of the apparent remainder will indicate the actual negative remainder.

Example: Subtract 362 from 127

Solution: Write

127 minuend
- 362 subtrahend

then

127 minuend
+ 638 tens complement of subtrahend

0 ⁝ 765 apparent remainder

= - 235 tens complement of apparent remainder

which is

- 235 actual negative remainder

SUBTRACTION BY COMPLEMENTS (BASE TWO).–Digital computers use the complementary addition technique for subtraction, which has been discussed in decimal notation; and they also use the base two system. The process for base two is similar to base ten.

The ones complement of a binary number is that number with all 1 digits changed to 0's and all the 0 digits changed to 1's. This process is termed inversion. Therefore, the ones complement of 10110 is 01001. The twos complement of a binary number is its ones complement plus 1; that is,

Number	Ones complement	Twos complement
01	10	11
111	000	001
1110	0001	0010

Notice that the number 01 plus its twos complement 11 equals 100 which is a 1 in the next higher place value column followed by zeros.

The twos complement may also be determined by inverting every digit after the first one (1); that is, starting with the smallest place value and moving toward the largest place value (right to left). This method is normally less time consuming than determining the ones complement and then adding one to form the twos complement. For example: the twos complement of

001101011 ⁝ 10 The first one (from
invert all ⁝ right to left) does
is ← - - - - - - - - -
110010100 ⁝ 10 not invert.

This indicates that the same procedure used for decimal numbers may be used for binary numbers to perform subtraction by the addition of the complement.

Problems: Find the ones and twos complements of the following binary numbers.

1. 101
2. 101101

Answers:

	Ones complement	Twos complement
1.	010	011
2.	010010	010011

Example: Subtract the binary number 01101 from the binary number 11001.

Solution: Write

11001 minuend
- 01101 subtrahend

then

11001 minuend
+ 10011 twos complement of the subtrahend

1 ⁝ 01100 difference

= + 01100 positive difference

Notice that the same number of place value columns must be used in both the subtrahend and minuend.

Example: In binary, subtract 1110 from 1111.

Solution: Write
1111 minuend
- 1110 subtrahend

then

1111 minuend
+ 0010 twos complement of the subtrahend

1 ⁝ 0001 difference

= + 0001 positive difference

As in the decimal system, if a one is developed, it indicates plus. If a zero is present, it indicates a negative apparent answer and the complement of the apparent answer is used, preceded by a minus sign.

Example: In binary, subtract 1011 from 1001.

Solution: Write

$$\begin{array}{rl} 1001 & \text{minuend} \\ \underline{-\ 1011} & \text{subtrahend} \end{array}$$

then

$$\begin{array}{rl} 1001 & \text{minuend} \\ \underline{+\ 0101} & \text{twos complement of the subtrahend} \\ 0\,1110 & \text{apparent difference} \\ -\ 0010 & \text{twos complement of the apparent difference} \\ -\ 0010 & \text{negative difference} \end{array}$$

Problem: Subtract in binary, using complementary addition.

1. 1101 from 1110
2. 111 from 10

Answers:

1. +0001
2. - 101

A verification of the preceding problems may be made by changing the binary numbers to decimal, carrying out the subtraction, then changing the difference back to binary.

This is as follows:

	binary		decimal
1.	1101	=	13
	1110	=	14

and

$$14 - 13 = 1 = 1_{(2)}$$

	binary		decimal
2.	111	=	7
	10	=	2

and

$$2 - 7 = -5 = 101_{(2)}$$

Multiplication

The direct method of multiplication of decimal numbers is shown in the following example.

Example: Multiply 32 x 25

Solution: Write

$$25 = 20 + 5$$

then

$$32\ (20 + 5)$$

Using the distributive principle

$$\begin{aligned} & 32\ (20 + 5) \\ = {} & 32\ (20) + 32\ (5) \\ = {} & 640 + 160 \\ = {} & 800 \end{aligned}$$

The same problem written as

$$\begin{array}{r} 32 \\ \underline{\times\ 25} \end{array}$$

gives

$$\begin{aligned} & 32 \times 5 \\ = {} & 160 \text{ partial product} \end{aligned}$$

and

$$\begin{aligned} & 32 \times 20 \\ = {} & 640 \text{ partial product} \end{aligned}$$

then

$$\begin{aligned} & 160 + 640 \\ = {} & 800 \text{ product} \end{aligned}$$

The technique generally used is

$$\begin{array}{r} 32 \\ \underline{\times\ 25} \\ 160 \\ \underline{64} \\ 800 \end{array}$$

Notice that the 64 really represents 640, but the zero is omitted.

Direct binary multiplication uses the same technique as direct decimal multiplication.

Example: Multiply the following binary numbers.

110 and 1101

Solution: Write

$$\begin{array}{r} 1101 \\ \underline{\times\ 110} \\ 0000 \\ 1101 \\ \underline{1101} \\ 1001110 \end{array}$$

This may be verified by changing the factors to decimal, multiplying and obtaining the decimal product, then changing the decimal product back to binary.

Problems: Multiply the following pairs of binary numbers.

1. 11 and 101
2. 11011 and 1011

Answers:

1. 1111
2. 100101001

Repetitive Addition

The idea that multiplication is repetitive addition is of beneficial use when working with computers. When multiplication is to be accomplished with a computer, the process of repeated addition is used.

If two numbers are to be multiplied together, write the following:

Multiply

231 by 45

Write

231 (40 + 5)

then

(231 x 40) + (231 x 5)

Multiplying each term gives the following:

$$\begin{array}{r} 231 \\ \underline{\times\ \ 40} \\ 9240 \end{array} \quad \text{and} \quad \begin{array}{r} 231 \\ \underline{\times\ \ 5} \\ 1155 \end{array}$$

Notice that 231 could have been added forty (40) times to satisfy one half of the above problem and 231 could have been added five (5) times to satisfy the other half.

$$\left.\begin{array}{r} 231 \\ 231 \\ 231 \\ 231 \\ '' \\ '' \\ '' \\ \underline{+\ 231} \end{array}\right\} \text{40 times} \qquad \left.\begin{array}{r} 231 \\ 231 \\ 231 \\ 231 \\ \underline{+\ 231} \end{array}\right\} \text{5 times}$$

$$\begin{array}{r} 9240 \end{array} \qquad\qquad\qquad \begin{array}{r} 1155 \end{array}$$

Rather than write 231 forty times, 2310 could have been written four times; that is,

$$\begin{array}{l} 231 \times 40 \\ = 231 \times 4 \times 10 \\ = 231 \times 10 \times 4 \\ = 2310 \times 4 \end{array}$$

$$\begin{array}{r} = 2310 \\ 2310 \\ 2310 \\ \underline{+\ 2310} \\ 9240 \end{array}$$

9240 + 1155 = 10395

When the repetitive addition type of multiplication is used in a computer, it would appear as follows. Two registers are used; that is, the accumulator and the multiplier. The accumulator maintains a constant subtotal and the multiplier keeps account of the addition to be performed.

The problem is to multiply 231 by 45.

Accumulator	Multiplier	
000000 + 000231	45	These operations represent the five ones
000231 + 000231	44	
000462 + 000231	43	
000693 + 000231	42	
000924 + 000231	41	
001155 + 002310	40	These operations represent the four tens
003465 + 002310	30	
005775 + 002310	20	
008085 + 002310	10	
0010395	00	

Notice that the multiplier indicated the number of times the number 231 was added and the accumulator maintained the subtotal. When the multiplier indicated 40, the 231 was changed to 2310 and the multiplier then would indicate addition of the 2310 four times. The overall effect was to move the zero in the 40 to the 231.

The binary system follows the previous techniques as shown in the following example. Multiply 1011 by 1101.

Accumulator	Multiplier
00000000	1101
+ 00001011	
00001011	1100
+ 00101100	
00110111	1000
+ 01011000	
10001111	0000

Division

The direct method of division of decimal numbers is shown in the following example:

Example: Divide 30 (dividend) by 5 (divisor).

Solution: Write

$$5\overline{)\,30}$$

Five is not contained in 3 but is contained in 30. How many 5's are contained in 30? The answer is 6, so write 6 above the zero

$$\begin{array}{r} 6 \text{ (quotient)} \\ 5\overline{)\,30} \end{array}$$

Multiply the 6 and 5 together and find the product which is 30. Write 30 under the 30 and subtract.

$$\begin{array}{r} 6 \\ 5\overline{)\,30} \\ \underline{30} \\ 0 \end{array}$$

There are no 5's in zero; therefore, the answer is 6.

Direct binary division follows the same procedure.

Example: Divide 1110 by 111.

Solution: Write

$$111\overline{)\,1110}$$

There is one 111 in 111 so write 1 above the right hand one in 111 as follows:

$$\begin{array}{r} 1 \\ 111\overline{)\,1110} \end{array}$$

Multiply 111 by 1 and write the product under the 111, and subtract, and bring down the last zero.

$$\begin{array}{r} 1 \\ 111\overline{)\,1110} \\ \underline{111} \\ 0000 \end{array}$$

There are no 111's in 0000; therefore, write zero after the 1 in the answer and find 10 is the answer.

$$\begin{array}{r} 10 \\ 111\overline{)\,1110} \\ \underline{111} \\ 0 \\ 0 \end{array}$$

Example: Divide 10010 by 110, all in binary.

Solution: Write

$$\begin{array}{r} 1 \\ 110\overline{)\,10010} \end{array}$$

Multiply quotient and divisor and subtract from dividend

$$\begin{array}{r} 1 \\ 110\overline{)\,10010} \\ \underline{110} \\ 11 \end{array}$$

Bring down last zero.

$$\begin{array}{r} 1 \\ 110\overline{)\,10010} \\ \underline{110} \\ 110 \end{array}$$

Find 110 goes into 110 one time and write

$$\begin{array}{r} 11 \\ 110\,\overline{)10010} \\ 110 \\ \hline 110 \end{array}$$

Multiply quotient and last dividend digit and find

$$\begin{array}{r} 11 \\ 110\,\overline{)10010} \\ \underline{110} \\ \hline 110 \\ 110 \\ \hline 000 \end{array}$$

and the answer is 11.

Problems: Divide the following binary numbers.

1. 10010 by 110
2. 10000111 by 101

Answers:

1. 11
2. 11011

Repetitive Subtraction

In multiplication, repeated addition is used; in division, repeated subtraction is used.

If one number (the dividend) is to be divided by another number (the divisor), write the following:

Divide. 126 by 6

Write

$$\begin{array}{r} 126 \\ -6 \\ \hline 120 \\ -6 \\ \hline 114 \\ -6 \\ \hline 108 \\ -6 \\ \hline " \\ " \end{array}$$

Subtracting 6 from 126 twenty-one times registers a zero remainder.

A computer does the same thing except it utilizes powers of ten.

Use is still made of the accumulator and register as in repetitive addition but the technique is operated in reverse order.

Example: Divide 40320 by 126.

Accumulator	Quotient register	
40320		(a) Put the dividend in the accumulator.
	0000	(b) Set the register to zero.
- 12600		(c) Put the divisor in the largest power of ten that is equal to or less than the value of the dividend that is in the accumulator.
	+ 0100	(d) Put the power of ten into the register.
27720		(e) Subtract.
	+ 0100	(f) Add the sums in the quotient register.
- 12600	+ 0100	(g) Repeat steps (c), (d), (e), and (f) as shown.
15120	0200	
- 12600	+ 0100	
2520	0300	
- 1260	+ 0010	
1260	0310	
- 1260	+ 0010	
0000	0320	Answer

Example: Divide 126 by 6.

Accumulator	Quotient register	
126	000	
- 60	+ 010	
066	010	
- 60	+ 010	
006	020	
- 6	+ 001	
000	021	Answer

The same procedure applies to binary division except the highest power of 2 (in binary) is used.

Example: Divide 100111 by 11.

Accumulator	Quotient register	
100111	00000	
- 11000	+ 01000	Add 2^3 to quotient register.
1111	01000	
- 1100	+ 00100	Add 2^2 to quotient register.
11	01100	
- 11	+ 00001	Add 2^0 to quotient register.
0	01101	Answer

CODING

As stated previously, electronic circuit elements of computers are inherently binary; that is, they will have two stable states. Therefore, the base ten numbering system cannot be used efficiently in computers. While people communicate and calculate using letters of the alphabet and numbers of the decimal system, digital computers communicate and calculate using groups of binary symbols called codes.

Coding is the means by which data in one form is represented in another form which is acceptable to the computer. A form of coding is used in the Morse code in which letters are represented by dots and dashes. This makes the alphabet acceptable to transmission by radio.

Of the many coding systems, three of the most common ones are discussed. It should be understood that memorization of these codes is not necessary, but the understanding of the reasons for the codes is desirable.

BINARY CODED DECIMAL (B.C.D.)

This code makes use of groups of binary bits (binary symbols) to represent a decimal digit. In the decimal system there are only ten digits; therefore, only ten groups of binary bits must be remembered, EACH DECIMAL DIGIT IS REPRESENTED BY A GROUP OF FOUR BINARY BITS. The ten groups to remember are as follows:

Decimal digit	Binary - coded decimal digit
0	0 0 0 0
1	0 0 0 1
2	0 0 1 0
3	0 0 1 1
4	0 1 0 0
5	0 1 0 1
6	0 1 1 0
7	0 1 1 1
8	1 0 0 0
9	1 0 0 1

To write ten in B.C.D., the use of two groups is required; that is,

Decimal	1	0
B.C.D.	0001	0000

Any two-digit decimal number requires two groups of B.C.D. etc.

Decimal	7	3	8
B.C.D.	0111	0011	1000

The separation of the B.C.D. groups is shown for ease of reading and does not necessarily need to be written as shown; 738 could be written as 011100111000. One advantage of the B.C.D. over true binary is ease of determining the decimal value. This is shown as follows:

B.C.D.	0111	0011	1000
= decimal	7	3	8

738 in true binary is 1011100010
and, true binary 1011100010

$$= \text{decimal } 1(2^9) + 0(2^8) + 1(2^7) + 1(2^6) + 1(2^5) + 0(2^4) + 0(2^3) + 0(2^2) + 1(2^1) + 0(2^0)$$

$$= 512 + 128 + 64 + 32 + 2 = 738$$

The ease of converting from decimal to B.C.D. and from B.C.D. back to decimal should be apparent in the following.

Problems: Convert the following decimal numbers to B. C. D.

1. 7
2. 4200

Answers:

1. 0111
2. 0100001000000000

Problems: Convert the following B. C. D. 's to decimals.

1. 010000110001
2. 0101000001111000

Answers:

1. 431
2. 5078

The comparative ease of conversion in B. C. D. is related to the difficulty of conversion in true binary by the following.

Problems: Convert

1. 438 to binary
2. 100101101 to decimal

Answers:

1. 110110110
2. 301

One serious disadvantage of the B. C. D. is that this code cannot provide a decimal carry. The following examples are given to show this.

Example: Add the following:

Decimal		B. C. D.
5	=	0101
+ 3	=	0011
8	=	1000

Notice that there was no carry in the decimal addition and the answer in B. C. D. is equal to the answer in decimal. The B. C. D. is in correct notation and does exist.

Example: Add the following:

Decimal		B. C. D.
8	=	1000
+ 5	=	0101
13	=	1101

Notice that the B. C. D. answer is correct in true binary, but $1101_{(2)}$ does not exist in B.C.D. The correct B. C. D. answer for 13 should be 0001 0011. Therefore, when a carry is made in decimal, the B. C. D. cannot indicate the correct answer in B. C. D. form.

Excess Three Code

The excess three code is used to eliminate the inability of the binary carry. It is really a modification of the B. C. D. so that a carry can be made.

To change a B.C.D. number to excess three, add three to the B. C. D. ; that is,

B. C. D.	1000
	+ 0011
Excess three	1011

In excess three code 1011 is 8 in decimal. The following chart shows the decimal, B. C. D., and the excess three code.

Decimal	B. C. D.	Excess three
0	0000	0011
1	0001	0100
2	0010	0101
3	0011	0110
4	0100	0111
5	0101	1000
6	0110	1001
7	0111	1010
8	1000	1011
9	1001	1100

As previously stated, the excess three code will provide the capability to carry in binary. The following is given for explanation.

Example: Add $6_{(10)}$ and $3_{(10)}$ in excess three.

Solution: Write

Decimal		Excess three with three groups possible
6	=	0011 0011 1001
+ 3	=	0011 0011 0110
9		

Notice that in group one the six and three are indicated. In groups two and three a zero (0011) in excess three is indicated.

Add as follows

0011	0011	1001	(Excess three)
0011	0011	0110	(Excess three)
0110	0110	1111	(Excess six)

But our answer is in excess six. Therefore, three must be subtracted from each group in order to return our answer to excess three.

0110	0110	1111	
- 0011	- 0011	- 0011	
0011	0011	1100	(Excess three)
0	0	9	Answer in decimal

When a carry is developed in any group, the following procedure is used.

Example: Add $9_{(10)}$ and $3_{(10)}$ in excess three.

Solution: Write

Decimal	Excess three				
9	0011	0011	1	1100	(Excess 3)
+ 3	0011	0011		0110	(Excess 3)
12	0110	0111		0010	(Excess 6)

NOTE: Since group one created a carry, as shown, three must be added instead of subtracted in order to place group one into excess three. The other groups follow the previous example.

0110	0111	0010	(Excess six)
- 0011	- 0011	+ 0011	
0011	0100	0101	(Excess three)
0	1	2	

The above procedure will hold for any number of group indicators the computer possesses.

Problems: Add the following numbers using excess three and give the answers in excess three with three indicator groups.

1. 5 and 3
2. 4 and 3
3. 58 and 77

Answers:

1. 0011 0011 1011
2. 0011 0011 1010
3. 0100 0110 1000

A further advantage of excess three code is the ease with which the nines complement of a number indicated in excess three may be found; that is, the nines complement of 7, indicated in excess three as 1010, is found by inverting each digit in 1010 to read 0101. This 0101, in excess three, is 2 which is the nines complement of 7.

The following table shows the nine complement of the decimal digits.

Decimal	Excess three	Excess three inverted	Nines complement
0	0011	1100	9
1	0100	1011	8
2	0101	1010	7
3	0110	1001	6
4	0111	1000	5
5	1000	0111	4
6	1001	0110	3
7	1010	0101	2
8	1011	0100	1
9	1100	0011	0

GRAY CODE

This code is a modification of the binary counting system. In the Gray code sequence counting, only one bit will change as each count proceeds. When counting in binary from $7_{(10)}$ $(0111_{(2)})$ to $8_{(10)}(1000_{(2)})$, notice that four bits had to be changed.

The Gray code is shown for comparison

Decimal number	Pure binary	Gray code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111

In the Gray code when counting from $7_{(10)}(0100)$ to $8_{(10)}(1100)$, notice that only one bit changed.

One of the primary purposes of this code is the reduction of operational errors by changing only one digit at the time during the process of converting mechanical changes into numerical expressions. For example, to convert the shaft rotation (output of an analog computer) from seven to eight degrees would require only a change of one bit as previously indicated.

To convert a binary code to its Gray code equivalent, the following addition WITHOUT CARRY is used.

Example: Convert binary 0100 to its Gray code equivalent.

Solution: Keep the most significant bit as is.

$$\begin{array}{lcccc} \text{Binary} & \boxed{0} & 1 & 0 & 0 \\ & \downarrow & & & \\ \text{Gray} & \boxed{0} & \_ & \_ & \_ \end{array}$$

Next, add horizontally the most significant bit to the next significant bit in the binary number and carry the sum to the Gray code as follows:

$$\begin{array}{lcccc} \text{Binary} & \multicolumn{2}{c}{\boxed{0\quad 1}} & 0 & 0 \\ & & \downarrow & & \\ \text{Gray} & 0 & \boxed{1} & \_ & \_ \end{array}$$

now add and continue as shown

$$\begin{array}{lcccc} \text{Binary} & 0 & \multicolumn{2}{c}{\boxed{1\quad 0}} & 0 \\ & & & \downarrow & \\ \text{Gray} & 0 & 1 & \boxed{1} & \_ \end{array}$$

then

$$\begin{array}{lcccc} \text{Binary} & 0 & 1 & \multicolumn{2}{c}{\boxed{0\quad 0}} \\ & & & & \downarrow \\ \text{Gray} & 0 & 1 & 1 & \boxed{0} \end{array}$$

Therefore, 0100 binary is equivalent to 0110 in the Gray code.

Example: Convert $14_{(10)}$ to Gray code.

Solution: Write

Decimal 14 = 1110 binary

$$\begin{array}{lcccc} \text{Binary} & \boxed{1} & 1 & 1 & 0 \\ & \downarrow & & & \\ \text{Gray} & \boxed{1} & \_ & \_ & \_ \end{array}$$

then

$$\begin{array}{lccccl} \text{Binary} & \multicolumn{2}{c}{\boxed{1\quad 1}} & & & \text{add without} \\ & & \downarrow & & & \\ \text{Gray} & 1 & \boxed{0} & \_ & \_ & \text{the carry} \end{array}$$

then

$$\begin{array}{lcccc} \text{Binary} & 1 & \multicolumn{2}{c}{\boxed{1\quad 1}} & 0 \\ & & & \downarrow & \\ \text{Gray} & 1 & 0 & \boxed{0} & \_ \end{array}$$

then

$$\begin{array}{lcccc} \text{Binary} & 1 & 1 & \multicolumn{2}{c}{\boxed{1\quad 0}} \\ & & & & \downarrow \\ \text{Gray} & 1 & 0 & 0 & \boxed{1} \end{array}$$

therefore, 1110 binary is equivalent to 1001 in Gray code.

Problems: Convert the following decimal numbers to the Gray code.

NOTE: This transition must include the binary code.

1. 12
2. 35

Answers:

1. 1010
2. 110010

A method is also needed to convert Gray code to binary code.

Example: Convert 1101 in Gray code to binary.

Solution:

$$\begin{array}{lcccc} \text{Gray} & \boxed{1} & 0 & 0 & 1 \\ & \downarrow & & & \\ \text{Binary} & \boxed{1} & \_ & \_ & \_ \end{array}$$

Retain the most significant Gray code bit.

$$\begin{array}{lcccc} \text{Gray} & 1 & \boxed{0} & 0 & 1 \\ & \nearrow & \downarrow & & \\ \text{Binary} & \boxed{1} & \underline{1} & \_ & \_ \end{array}$$

Add diagonally without a carry.

$$\begin{array}{lcccc} \text{Gray} & 1 & 0 & \boxed{0} & 1 \\ & & \nearrow & \downarrow & \\ \text{Binary} & 1 & \boxed{1} & \underline{1} & \_ \end{array}$$

Continue diagonal addition

$$\begin{array}{lcccc} \text{Gray} & 1 & 0 & 0 & \boxed{1} \\ & & & \nearrow & \downarrow \\ \text{Binary} & 1 & 1 & \boxed{1} & \underline{0} \end{array}$$

Continue.

Therefore, Gray 1001 is equivalent to binary 1110.

Problems: Convert the following gray codes to binary.

1. 10000
2. 0001

Answers:

1. 11111
2. 0001

OCTAL NUMBERS

Octal numbers are base eight numbers; that is, there are only eight digits in base eight. These are 0, 1, 2, 3, 4, 5, 6, and 7. Because eight is a power of two, the octal system has special characteristics that make it especially useful in situations involving binary numbers. This is illustrated as follows:

A decimal number can be converted to octal by the same method described for decimal to binary; that is, to change 334 to octal write

8 /334   Remainder
8 /41   6 ↑
8 /5   1
0   5

Therefore,

334 decimal = 516 octal or $516_{(8)}$

The same decimal number when changed to binary is 101001110.

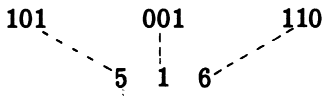
Since things equal to the same thing are equal to each other

$$516_{(8)} = 101001110_{(2)}$$

Notice that the true binary number is separated into groups of three digits from the right as follows:

101   001   110

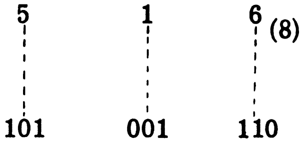
and by observation, notice that each group represents the following:



which is 516 in octal.

To convert from binary to octal, it is only necessary to divide the binary number into groups of three and read each group as the octal representation in place value.

To convert from octal to binary, the reverse operation is used; that is,



Example: Convert 40 decimal to octal, then to binary.

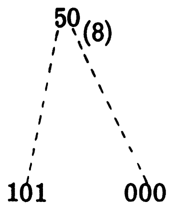
Solution: Write

8 /40   Remainder
8 /5   0 ↑
5

Therefore,

$$40_{(10)} = 50_{(8)}$$

and then



The preceding conversions from binary to octal and from octal to binary are possible because 2^3 is the same as 8^1.

Problems: Convert the following binary numbers to octal.

1. 101101
2. 1110110

Answers: (In base eight)

1. 55
2. 166

Problems: Convert the following octal numbers to binary.

1. 482
2. 761

Answers: (In binary)

1. Impossible to have an 8 in base eight (is not an octal number).
2. 111110001

The octal number system affords many conveniences. When recording a binary number on paper, it is usually more convenient to write it in octal. For example, computer programers and programing manuals use the octal system as a convenient notation for binary numbers. Also, when converting a large decimal number to binary, it is usually more convenient to convert it to octal first and then to binary since fewer divisions are required in dividing a decimal number by 8 instead of 2.

A number in any base that is smaller than ten can be converted to a number in base ten (decimal) by the following method: Multiply the most significant digit (MSD) by the present (old) base, add the next MSD to the product of the last multiplication and multiply the sum by the present (old) base, continuing until the least significant digit (LSD) is added.

EXAMPLE: Convert
to decimal 362
↓ (8)
3
8
24 + 6 = 30
8
240 + 2 = 242

INPUT AND OUTPUT DEVICES

An analog device yields an output in the form of a varying voltage, current, resistance, or mechanical shaft rotation. This form of output is unusable as an input to a digital computer. Since the majority of military indicating devices are of the analog type, their outputs must be converted to be used as inputs for the digital computers.

INPUT DEVICES

An input device is considered to be any device which yields an output which is usable for the particular computer it feeds. The devices which will be discussed are referred to as converters or encoders because they convert analog information into digital information.

V-Scan Converter

The V-scan converter continuously converts a changing mechanical position (analog information) into pulses (binary information) with an accuracy of plus or minus one bit (binary digit).

The basic method of converting a mechanical position into a binary code involves an arrangement of brushes and contacts. The mechanical movement positions the brushes relative to the contacts. The conducting contacts contain a voltage level which represents a binary 1 and the insulating contacts contain no voltage which represent a binary 0. The contact arrangement necessary to produce a natural binary code ranging from 0 to 15 is illustrated in figure 11-1.

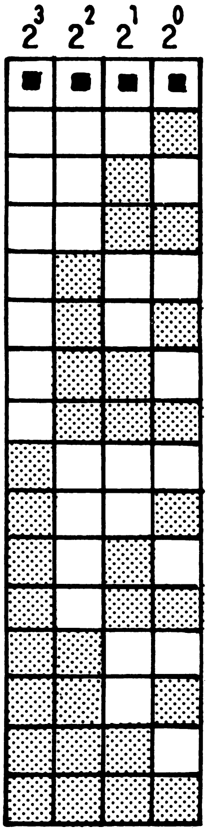


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Figure 11-1.–Natural binary code contact arrangement.

NOTE: For the purpose of discussion, consider the contact arrangement in figure 11-1 as being attached on the side of a tank containing a liquid. The brushes are controlled by the level of the float which varies with the level of the liquid in the tank. Notice that, as shown, when the brushes move downward, a binary indication of the amount of liquid expended is indicated. The dark areas are conducting contacts and the light areas are insulating contacts. The four squares at the top of the contact arrangements represent four in-line brushes. The position of the in-line brushes, as shown, indicate a binary 0000 or zero. The analog output moves the brushes down the contacts to indicate any binary number from 0000 (zero) to 1111 (fifteen).

Unfortunately, there is an ambiguity associated with the use of the in-line brushes and the natural binary code. This problem arises at any point where two or more brushes are required to switch at the same moment from one type of contact to the other; that is, from conducting to insulating or from insulating to conducting.

Figure 11-2 shows a portion of a four-bit binary coding plate and reveals the exact nature of the problem. Note that the brush positions that are indicated by x's are reading a 6 (0110). At this instant the brushes are obviously providing the correct reading. Examination of the next position of the brushes, indicated by y's, however, reveals ambiguous readings. For this example, the brush position is at the switching point from 7 (0111) to 8 (1000). The brush in the 2^3 column is making contact with the conducting material, while brushes in the 2^0, 2^1, and 2^2 columns are still making contact with the conducting material. The output from the brushes at this time is 15 (1111), which should not occur when moving from 7 (0111) to 8 (1000). This produces an erroneous reading. Note that erroneous readings are also obtainable at the 9 to 10 switching point and at the 11 to 12 switching point.

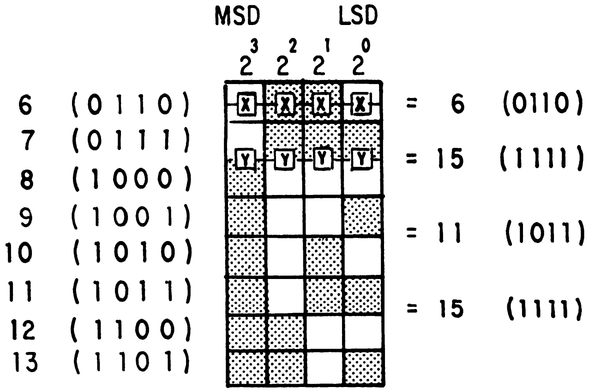

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Figure 11-2. –Ambiguity with the natural binary code.

Obviously, the possibility of reading a 15 when it should actually be switching from 7 to 8 (or reading 11 when it should be switching from 9 to 10, or of reading any of the other ambiguous numbers that may be produced) makes it impossible to read instantaneous values with any high degree of certainty. The major factors in determining the accuracy of the natural binary-coded converter are the positioning of the contacts, the positioning of the brushes, the size of the contacts, and the thickness of the brushes. The perfect converter, in order to preclude ambiguities, would have each contact exactly in its required position, all brushes in a straight line perpendicular to the direction of movement, all contacts exactly the same size, and the brushes infinitesimally narrow and exactly uniform. Meeting the prestated requirements for a perfect converter is a physical impossibility.

The V-scan converter employs a method of conversion whereby the physical requirements allow almost perfect conversion. This is accomplished by the use of a double brush (except for the 2^0 column brush) system. The particular relationship between the brushes is predetermined. The direction of movement to be used when describing one set of brushes as leading and one set of brushes as lagging is determined by the design of the grid. In figure 11-3 the direction which will determine the leading or lagging brushes is downward. This direction must be used regardless of whether the float is causing the brushes to move downward or upward. This may occur when filling or emptying the tank.

When reading the brush positions from right to left, two rules are followed:

1. If a bit is read as a one (electrical contacts touching) in a place value column, the next larger place value column is read on the lagging brush.
2. If a bit is read as a zero (nonconducting contact) in a place value column, the next larger place value column is read on the leading brush.

The determination of whether a leading or lagging brush is used at any particular time is a design function of this converter and will not be discussed.

Since the least significant digit (LSD) column has but one brush, it will always be the reference. As shown in each section of figure 11-3, there are some brushes that are touching conducting and nonconducting segments at the same time. By applying the previously stated rules, figure 11-3 (A) is read as follows:

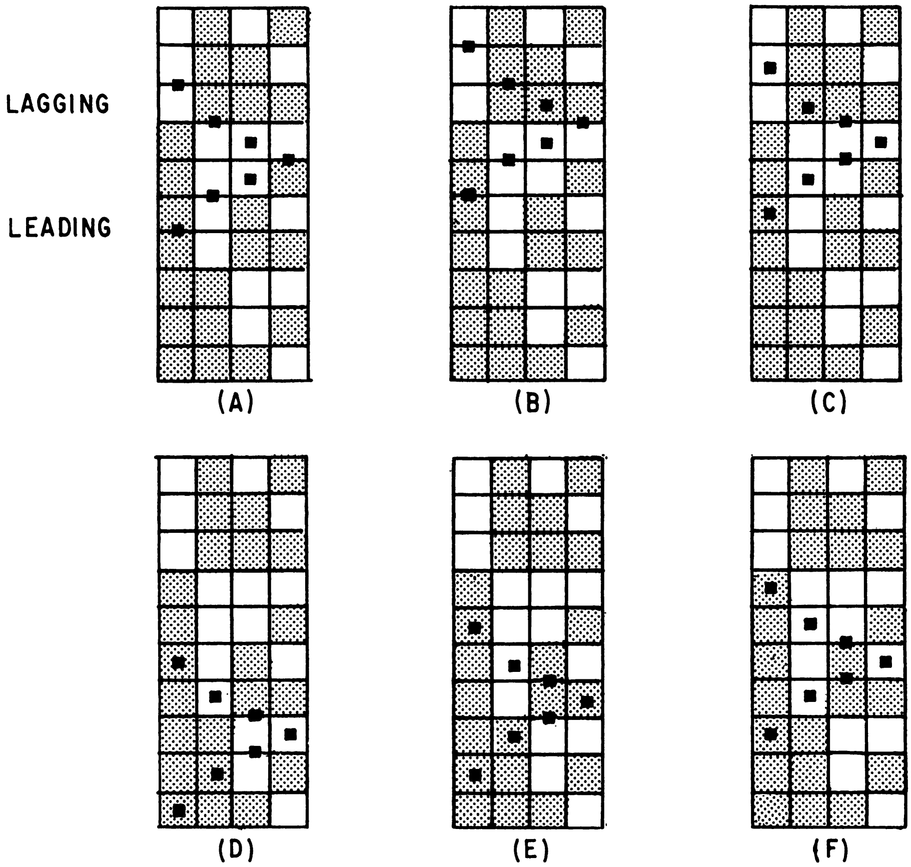

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Figure 11-3. –Natural binary code contact arrangement showing V-scan brushes.

Column 1: This is our reference brush and since it is conducting a binary 1 is read.

Column 2: Read the lagging brush position because column 1 brush was conducting. The lagging brush position indicates a zero.

Column 3: Read the leading brush position because column 2 brush was not conducting; therefore, a zero is read for column 3.

Column 4: Read the leading brush position which indicates a zero. Therefore, figure 11-3 (A) is indicating $1001_{(2)}$ or $9_{(10)}$.

The following sections of figure 11-3 indicate:

Figure 11-3 (B) – $0111_{(2)}$ or $7_{(10)}$

Figure 11-3 (C) – $1000_{(2)}$ or $8_{(10)}$

Figure 11-3 (D) – $1100_{(2)}$ or $12_{(10)}$

Figure 11-3 (E) – $1011_{(2)}$ or $11_{(10)}$

Figure 11-3 (F) – $1010_{(2)}$ or $10_{(10)}$

BINARY WHEEL. –The binary wheel is a basic application of converting shaft rotation (analog) to binary (digital) information.

The binary wheel is a plane comprised of concentric circles, with each ring divided into twice as many sectors as the adjoining inner ring. A close examination of figure 11-4 will show that it is really the previous rectangular set of contacts (fig. 11-2) set up in concentric rings. If the brushes are located in a straight line, as shown in figure 11-4, the same difficulty of erroneous indications will be present as the brushes move around the circles.

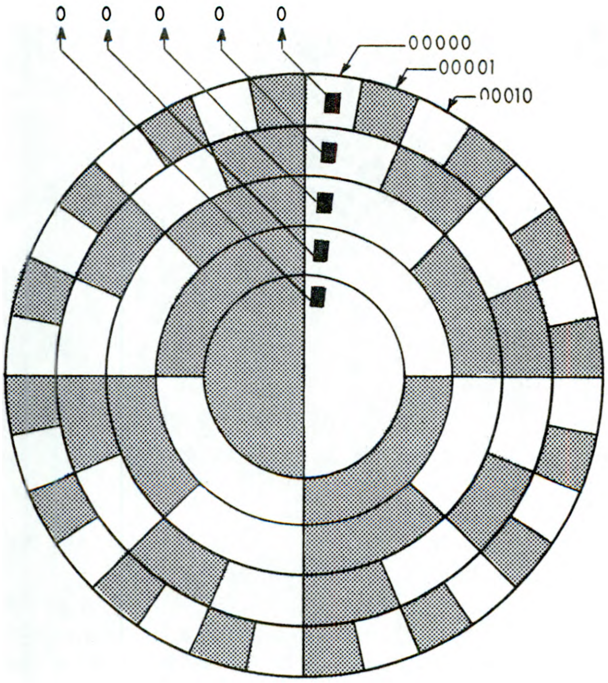

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Figure 11-4. –Simple five-bit shaft encoder.

By installing dual brushes in all rings except the outer (least significant digit) ring, as shown in figure 11-5, and properly placing the brushes, the erroneous readings may be eliminated. The number indications are read as previously indicated for the V-scan readings. The direction of rotation of the disk determines which set of brushes will be leading or lagging–in this case, clockwise.

Shaft Position Encoder

Shaft position encoders are electromechanical devices used to generate a binary number representing the angular position of an attached shaft. This encoder shaft is usually connected to the shaft of a motor or potentiometer via a gear train.

Figure 11-6 illustrates the type of shaft position encoders used in the Ballistic Computer Set ASQ-61A, installed in the A-6A aircraft.

The shaft position encoder used in this system is discussed more thoroughly later in the chapter under INPUT UNITS.

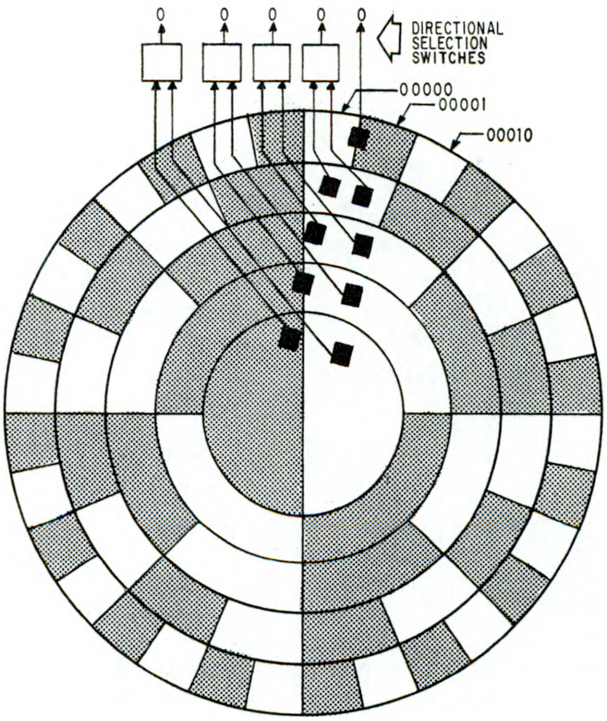

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Figure 11-5. –Five-bit V-scan encoder.

Bindary Gray Coded Grid

Figure 11-7 shows a grid (coded in the Gray code) with five brushes. The shaded blocks indicate 1 binary, and the blank blocks indicate 0 binary. This is the same as previously used. Notice that as the brushes (x) move down the grid, only one brush will change its state (conducting to nonconducting or nonconducting to conducting) as the number is increased by one.

The brushes are shown to be indicating two in Gray binary; and as they move to 3 Gray binary, only one brush changed state. In figure 11-2 the movement from 7 to 8 caused an erroneous reading. Notice that as the brushes (y) shown in figure 11-7 move from 7 to 8, an erroneous reading does not occur because only one brush changed state.

BINARY GRAY CODED WHEEL. –Figure 11-8 shows the binary Gray coded wheel in which angular position of the brushes is represented by a Gray coded number. In changing from one number to the next, only one brush changes state. Notice that one set of brushes allows

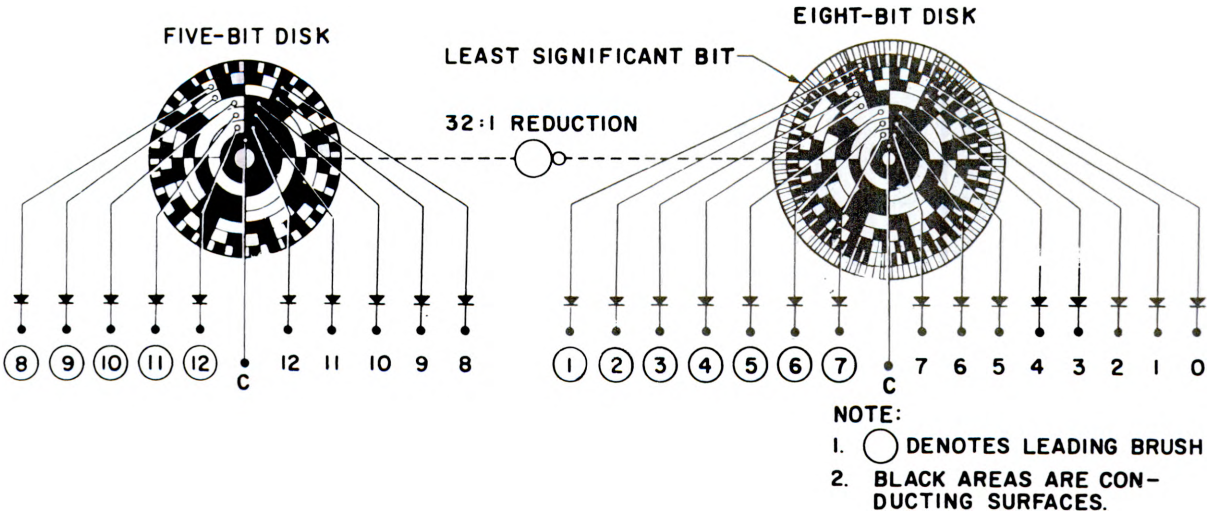

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Figure 11-6. –Shaft position encoder disks, placement of brushes.

indications in sequential steps without ambiguous readings when moving from one number to the next.

In figure 11-8, the brush reading line shows the reading to be 01001 in Gray code. This indication could represent bearing, speed, direction, or any of many analog positions.

Brush Encoder Problems

The disadvantages of brush type encoders are early and frequent failures caused by excessive brush and disk wear, frequent miscounting, critical brush alinement, and low operating speeds. Brushes are susceptible to vibration and acceleration forces that can cause intermittent contact and shifts in brush position. High rotational speeds cause wear of the brushes and particle contamination of the code disk, which lead to a diminution of accuracy. Brush bounce at high speeds may be severe, resulting in extraneous pulse outputs. Although a compromise may be reached by an increase in brush-contact pressure, this also increases the load torque, aggravates the problem of wear of the brush contacts, and reduces life of the code wheel. The results are encoders which are unreliable, have a short useful life, require frequent and costly maintenance and/or replacement, and are limited in operating speed.

Optical Encoders

In optical encoders, there are no contacting surfaces other than bearings. Photocells are used to detect light from a light source through a code disk which has alternately opaque and transparent segments. Electronic amplifying, discriminator, and logic circuitry is required to obtain the desired digital output. Continuous low-voltage d-c tungsten lamps are usually used as the light source, which has a predicted life of over 10,000 hours. The mean-time-between-failure (MTBF) of optical encoders is at least 10 times greater than that of comparable brush encoders.

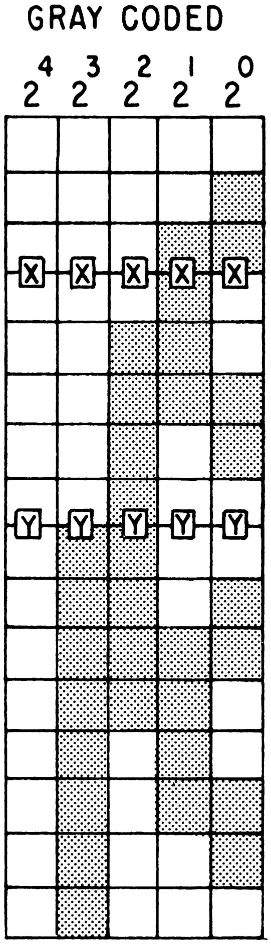
OUTPUT DEVICES

Input and output devices are similar in operation but perform opposite functions. It is through the use of these devices that the computer is able to communicate.

Output information is also made available in three types: human information, such as codes or symbols presented on a cathode-ray screen which are used by the operator to answer questions or make decisions; information which operates a control device such as a level, aileron, or actuator; or information which is stored in a machine language or human language, on tapes, printed media.

Wheel Displays

Any one of the angle to number converters previously described can be connected as an output device, either to furnish an angle signal or



GRAY	BINARY	DECIMAL
00000	0 0 0 0 0	0
00001	0 0 0 0 1	1
00011	0 0 0 1 0	2
00010	0 0 0 1 1	3
00110	0 0 1 0 0	4
00111	0 0 1 0 1	5
00101	0 0 1 1 0	6
00100	0 0 1 1 1	7
01100	0 1 0 0 0	8
01101	0 1 0 0 1	9
01111	0 1 0 1 0	10
01110	0 1 0 1 1	11
01010	0 1 1 0 0	12
01011	0 1 1 0 1	13
01001	0 1 1 1 0	14
01000	0 1 1 1 1	15

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Figure 11-7.–Binary Gray Coded grid.

display (pointer or servo signal) or to mechanically position a particular symbol on a wheel display. The symbol to be displayed can be any arbitrary number, letter, word, or other symbol selected by the designer.

The wheel can be positioned by a servomotor, by a step counting switch, by a digital to analog converter coupled with a motor, etc. The only limitation on the positioning system is that it must be able to drive the wheel until the correct symbol is displayed.

The display may be generated by wheels geared together in a fixed ratio (as in an odometer) or with each wheel individually driven and positioned. A disadvantage of the second system is the increased space required to accommodate the separate drive mechanisms. The number of symbols to be displayed is limited by the size of the wheel and by the number of discrete positions that can be selected.

Practically any encoder can be used as a decoder (digital-to-analog converter) either directly or by positioning it with a null-seeking driver.

Lights

Each individual light may be considered as the equivalent of a binary stage: ON–true or one; OFF–false or zero. Lights are used to display such discrete data as failsafe, on-off, and warning. They may be used in groups and in conjunction with ring counters to form binary to decimal conversion displays. Each individual

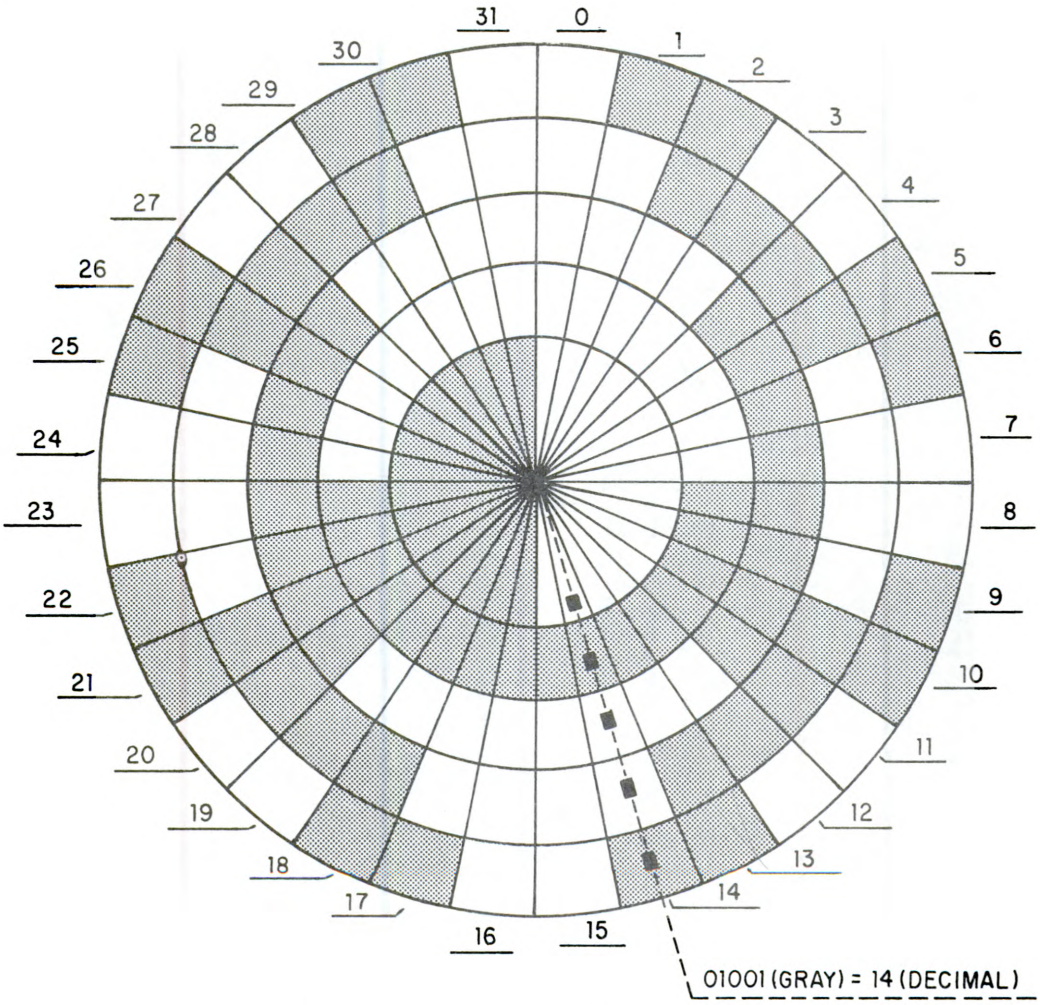

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Figure 11-8. –Binary Gray coded wheel.

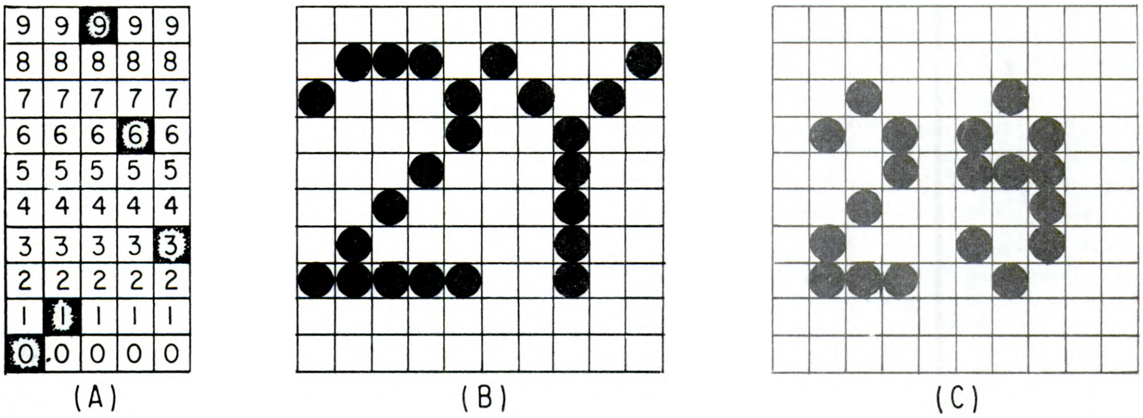

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Figure 11-9. –Light displays.

light is sequenced and illuminates the appropriate digit when switched on by the counters. (See fig. 11-9 (A).)

MULTIFILAMENT LIGHTS. - These lights may display numbers, letters, symbols, or combinations of these. Filaments may "edge light" lucite cards to illuminate engraved symbols, or may actually be shaped in the form of the symbol and glow when switched on. (See figure 11-9 (B) and (C).)

Lights require appreciable current–greater than that which is normally available directly from the computing circuits. Therefore, a buffer or amplifier stage is usually required to furnish the additional current. Since a single display illuminates multiple symbols and requires at least one terminal for each, it may require its own counter circuits to convert from binary code to the display code, or it may share a common converter with several other circuits. On the other hand, the individual filaments may be prewired to a printed circuit board, and the appropriate display selected and switched by computer circuitry.

The value or quantity being measured may be represented by a positioned display of multiple filament lights. The digital voltmeter is a fairly common example of the use of these lights.

BALLISTICS COMPUTER SET AN/ASQ-61A

The Ballistics Computer Set AN/ASQ-61A, which is installed in the A-6 type aircraft, is discussed briefly in this chapter. Due to the complexity of the system, no circuit analysis is covered. Computer operation, input controls, programed operating modes, and the functional divisions of the computer are discussed for a familiarization only with the system and its capabilities.

The ballistics computer is the center of the INTEGRATED ATTACK-NAVIGATION SYSTEM. The computer provides flight pattern data, navigation cruise commands, and information to aid in the selection, fuzing, and delivery of weapons. The ballistics computer solves, continuously and automatically, all necessary ballistic equations to deliver any assigned weapon. In the newer models of the A-6 aircraft, the cruise control, mapping, Doppler, and external control functions are deleted. The ballistics function has been revised and the release-advance capability, and self-test clock delay and bit count function has been added.

COMPUTER PROGRAMS

The Ballistics Computer Set AN/ASQ-61A is a digital computer and therefore requires a set of operating instructions known as a program. This program is kept in permanent storage in the computer memory drum and may be changed only by means of a special drum fill device. Changes are made periodically to reflect changes made to the aircraft, to incorporate new weapons, or to add to the versatility of the weapons system. These programs are identified by the letter P followed by a number which indicates the particular program position in the order of development. Thus, the P 7 is a later program than P 6. Revisions to a program are designated by a suffix letter; e.g., P 7A, P 7B. The current programs in use at the present time are P 7, P 7A and P 7B. The difference in the current programs are discussed further under the description of the various systems that are affected. The basic steps used in computer programing are discussed at the end of this chapter.

COMPUTER OPERATION

The computer receives signals from the major components of the system and translates these into information for subsequent operation. The computer continuously evaluates the various inputs with respect to the solution of the ultimate bombing problems. (See fig. 11-10.) It samples the settings of all the weapons stations, and applies proper stores ballistics data and equations. The computer utilizes wired-in logic in the armament panel and insures appropriate weapon selection and arming.

Computer outputs generate and control various displays available to the pilot and bombardier/navigator (B/N). These include contact analog, radar cursor positioning, steering bugs, optical sight, terrain clearance, and tape dial readouts which provide information of various types to the crewmembers. The system utilizes 115/200-volts, 400 Hz, 3-phase power generated by the aircraft and has internal power supplies generating the other voltages required for system operation.

INPUT CONTROLS

The various input controls for the integrated attack-navigation system are on the flight mode selector panel, the keyboard control panel, and the navigation control panel. The functions of these panels and their associated controls are briefly discussed in the following paragraphs.

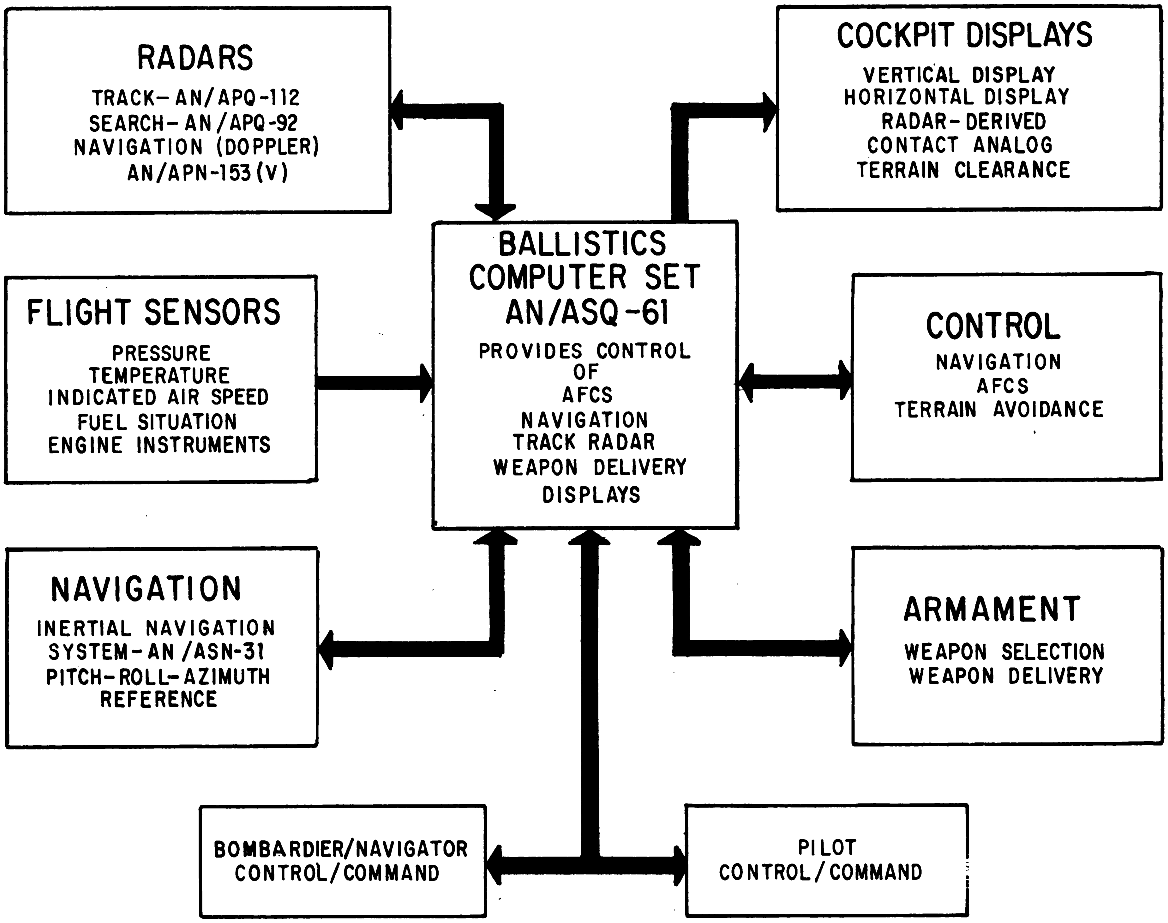

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Figure 11-10. –Integrated attack-navigation system.

FLIGHT NAVIGATION MODE PANEL

The flight navigation mode selector panel (fig. 11-11) is on the B/N's control panel. This panel contains the necessary controls for selecting the mode of operation of the computer and associated functional readouts for navigation purposes.

Flight Mode Selector Buttons

The computer selector buttons are six push-buttons on the flight navigation mode panel, and are placarded TEST, OFF, PRE FLT, TAKE OFF, FLIGHT, and LAND. These buttons are used to select the type of data the computer is to provide, and they require positioning prior to

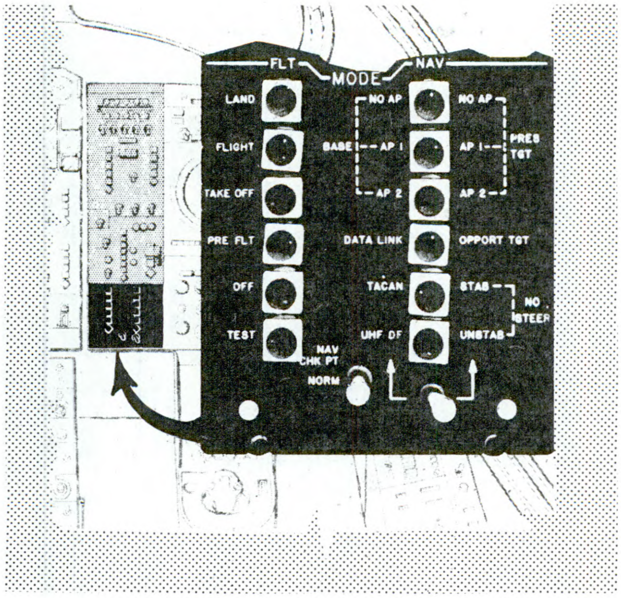

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Figure 11-11. –Flight navigation mode selection panel.

inserting mission data by the B/N. The buttons are of the square-coded type, and are spring loaded so that only one button can be depressed at any one time. The buttons rotate 45° when depressed, to indicate the mode presently selected.

With the OFF button depressed, the system is inoperative, with no power applied to the computer components.

The PRE FLT button is used for ground check. It enables operational testing of the ballistics computer prior to takeoff.

Depressing the TAKE OFF button instructs the ballistics computer to present dead-ahead commands to the pilot. This button is depressed when the aircraft is alined with the runway and is ready for takeoff.

The FLIGHT mode is the normal operating mode. It is used to initialize the computer and for insertion of navigation and performance data prior to takeoff. It is activated again after takeoff and utilized during the navigational and attack portion of the mission.

Depressing the LAND button instructs the ballistics computer to present to the pilot landing information relative to either a carrier or a runway. The basic information for this pathway is developed from data inserted into the computer. The TEST position on the flight navigation mode panel permits testing the various components of the computer to insure proper operation, and is primarily a function of maintenance.

Navigation Mode Selector Buttons

The six selector pushbuttons on the flight navigation mode panel (fig. 11-11) allow the B/N to position the radar cursors over a preselected point. Steering information is provided for the pilot depending on the mode selected (fig. 11-12).

There are two settings for each of the pushbuttons, depending upon the position of the navigation transfer switch below the lower pushbutton (fig. 11-11). When the navigation transfer switch is positioned to the left, the following functions may be selected:

1. BASE - NO AP (Base - No Aimpoint)–Depressing the BASE - No AP button instructs the computer to provide the necessary steering information to the pilot's displays and positions the radar cursors to the previously inserted latitude and longitude of the base which the pilot intends to land.

2. BASE - AP 1 (Base - Aimpoint 1) – Depressing the BASE - AP 1 button instructs the computer to provide the necessary steering information to the pilot's displays to direct the aircraft to the previously inserted latitude and longitude of the base, and simultaneously to position the radar cursors to an offset aimpoint of previously inserted range and bearing from the base.

3. BASE - AP 2 (Base - Aimpoint 2)–With this button depressed, the computer provides information as outlined in BASE - AP 1, except that the radar cursors are directed to a second offset aimpoint. When using this control in either position, the aimpoint is selected because of its better radar return characteristics.

UNSTAB-NO STEER

When the navigation transfer switch is positioned to the right, the following functions may be selected:

1. PRES TGT - NO AP (Preset target - No Aimpoint)–Depressing the PRES TGT - NO AP Button instructs the computer to provide the necessary steering information to the pilot's displays and positions the radar cursors to the previously inserted latitude and longitude. The altitude entered for this location is also used by the computer when OPPORT TGT is selected.

STEERING OPTIONS	NAVIGATION PANEL "ON CALL" READOUT	PHD RANGE INDICATOR	RADAR CURSORS POSITION TO	PHD BUG POINTS TO	DVI BUG POINTS TO	VDI STEERING COMMANDS TO	REMARKS	* DV RANGE D INDICAT
BASE NO AP	KEYBOARD INPUTS OF LAT, LONG, ALT OF BASE	GROUND RG TO BASE	COORDINATES OF BASE	DRIFT CORRECTED HEADING TO BASE	TRUE BRG TO BASE NO AP	COORDINATES OF BASE	RADAR CURSORS ARE POSITIONED BY THE COMPUTER, BUT CAN BE SLEWED BY THE B/N.	TO BASE
BASE API	KEYBOARD OR TRACK RADAR DERIVED INPUTS OF LAT, LONG, ALT OF BASE	↓	AIMPOINT 1 BASE	↓	TRUE BRG TO BASE AP1	↓	↓	TO AIMPOINT 1 UNDER 16.5 MILES TO BASE OVER 16.5 MILES
BASE AP2	↓	↓	AIMPOINT 2 BASE	↓	TRUE BRG TO BASF AP2	↓	↓	TO AIMPOINT 2 UNDER 16.5 MILES TO BASE OVER 16.5 MILES
PRES TGT NO AP	KEYBOARD INPUTS OF LAT, LONG, ALT OF TGT	GROUND RG TO TGT	COORDINATES OF TARGET	DRIFT CORRECTED HEADING TO TGT	TRUE BRG TO TGT NO AP	COORDINATES OF TGT	↓	TO TGT
PRES TGT AP1	KEYBOARD OR TRACK RADAR DERIVED INPUTS OF LAT. LONG, ALT OF TGT	↓	AIMPOINT 1 TARGET	↓	TRUE BRG TO TGT AP1	↓	↓	TO AIMPOINT 1 UNDER 16.5 MILES TO TARGET OVER 16.5 MILES
PRES TGT AP2	↓	↓	AIMPOINT 2 TARGET	↓	TRUE BRG TO TGT AP2	↓	↓	TO AIMPOINT 2 UNDER 16.5 MILES TO TARGET OVER 16.5 MILES
OPT TGT	LAT, LONG, OF CURSOR INTERSECTION KEYBOARD OR TRACK RADAR DERIVED TGT ALT	GROUND RG TO CURSOR INTERSECTION	POSITIONED BY SLEW CONTROL AND GROUND STABILIZED	DRIFT CORRECTED HEADING TO CURSOR INTERSECTION	ALIGNED WITH AZIMUTH CURSOR	CURSOR INTERSECTION	RADAR CURSORS ARE POSITIONED BY THE B/N	CURSOR INTERSECTION
UNSTAB NO STEER	↓	12.5 MILES	FIXED AT 12.5 MILES SLANT RANGE ALONG AIRCRAFT HEADING	AIRCRAFT HEADING	AIRCRAFT HEADING	NO STEERING ORIENTATION	RADAR CURSORS ARE POSITIONED BY THE COMPUTER BUT CAN BE SLEWED BY THE B/N	75,940 SLANT RANGE
STAB NO STEER	↓	GROUND RG TO CURSOR INTERSECTION	POSITIONED BY SLEW CONTROL AND GROUND STABILIZED	AIRCRAFT HEADING	AIRCRAFT HEADING	NO STEERING ORIENTATION	RADAR CURSORS CAN BE POSITIONED BY THE B/N	75,940' SLANT RANGE (INITIALLY)
TACAN **	↓	GROUND RG TO TACAN STATION (UP TO 198 MILES)	RANGE AND TRUE BRG TO STATION SELECTED	DRIFT-CORRECTED HEADING TO TACAN STATION	TRUE BRG TO TACAN STATION	DRIFT CORRECTED STEERING TO TACAN STATION	WHEN UNDER 6 MILES TO STATION, THE COMPUTER "MEMORIZES" STATION'S COORDINATES TO AVOID LOSING LOCK-ON B/N LOSES CURSOR CONTROL	TACAN STATION (UP TO 198 MILES)
UHF-DF **	↓	0	0 MILES AND TRUE BRG TO STATION SELECTED	DRIFT-CORRECTED HEADING TO STATION	TRUE BRG TO STATION	DRIFT CORRECTED STEERING TO UHF STATION	B/N LOSES CURSOR CONTROL	0
NAV CHK POINT	KEYBOARD INPUTS OF LAT, LONG, ELEV OF NAV CHECKPOINT	GROUND RG TO CURSOR INTERSECTION	COORDINATES OF CHECKPOINT	DRIFT-CORRECTED HEADING TO TGT (OR BASE)	TRUE BRG TO CHECK-POINT	DRIFT CORRECTED STEERING TO TGT (OR BASE)	USED BY B/N TO CORRECT PRESENT POSITION INFORMATION WITHOUT AFFECTING PILOT'S COMMAND STEERING	CURSOR INTERSECTION

NOTE

* DVI STEERING GROUND RANGE IN MILES IF OVER 16.5 NAUTICAL MILES; SLANT RANGE IS IN FEET UNDER 16.5 NAUTICAL MILES.

** INOPERATVE IN AIRCRAFT INCORPORATING THE P 7 OR P 7 A PROGRAM. SELECTION RESULTS IN UNSTAB NO STEER

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Figure 11-12. –Navigation steering options.

2. PRES TGT - AP 1 (Preset target - Aimpoint 1)–Depressing the PRES TGT - AP 1 button instructs the computer to provide the necessary steering information to the pilot's displays to direct the aircraft to the previously inserted latitude and longitude of the target and simultaneously to position the radar cursors to an offset aimpoint of previously inserted range and bearing from the target position.

3. PRES TGT - AP 2 (Preset target - Aimpoint 2)–With this button depressed, the computer provides information as outlined in PRES

TGT - AP 1, except that the radar cursors are directed to a second offset aimpoint. When using either of these positions, the aimpoint is selected because of its better radar return characteristics.

4. OPPORT TGT (Opportunity Target)–Depressing this button instructs the computer to present steering information toward the intersection of the radar cursors. The altitude used by the computer with OPPORT TGT selected is that inserted for PRES TGT NO AP. In aircraft incorporating the P 7 program, this altitude may be changed by simply inserting a new altitude for PRES TGT NO AP.

5. STAB - NO STEER (stabilized - No Steering)–Depressing this button instructs the computer to provide no steering instructions to the aircraft systems, and simultaneously to ground stabilize the radar range and azimuth cursors at any position selected by the B/N through the operation of the slew control stick.

In aircraft with the P 7 or P 7A program, the cursors will be left at the 12.5-mile dead-ahead position. Cycling steering with the navigation checkpoint switch leaves the cursors at the checkpoint.

6. UNSTAB - NO STEER (Unstabilized - No Steering–Depressing this button sets the relative bearing of all steering commands to zero (dead ahead), and positions the range and azimuth cursors at a point 12.5 miles dead ahead of the aircraft. The cursors are unstabilized in range and azimuth.

When UNSTAB - NO STEER is selected and steering is cycled with navigation transfer switch, the cursors will remain at the 12.5-mile dead-ahead position. If steering is cycled with the navigation checkpoint switch, the cursors will return to the 12.5-mile dead-ahead position.

Navigation Transfer Switch

The navigation transfer switch is a two-position toggle switch below the lower pushbutton (fig. 11-11). The switch has no placarded positions and, when moved to the left or right, enables selection of two groups of six ballistics computer navigational modes using the same six navigation mode selector buttons.

Navigation Checkpoint Switch

This two-position toggle switch (fig. 11-11), placarded NAV CHK PT (navigation checkpoint) and NORM (normal), provides a means of suspending all instructions from the navigation mode selector buttons, except pilot's steering information. When the switch is positioned to NAV CHK PT, the computer directs the radar range and azimuth cursors to the navigation checkpoint previously inserted into the computer. In this position, the computer steering information provided the pilot will not be interrupted; however, range information is to the checkpoint and pilot steering is to an infinite range. The displays will continue to provide the pilot with the necessary steering information.

NOTE: To update information in this mode, the B/N positions the cursors over the predetermined checkpoint and depresses the CORRECT POS button on the navigation control panel. This will automatically correct all present position readouts, except altitude.

With the switch in the NORM position, the computer operates as directed by the navigation mode selector buttons.

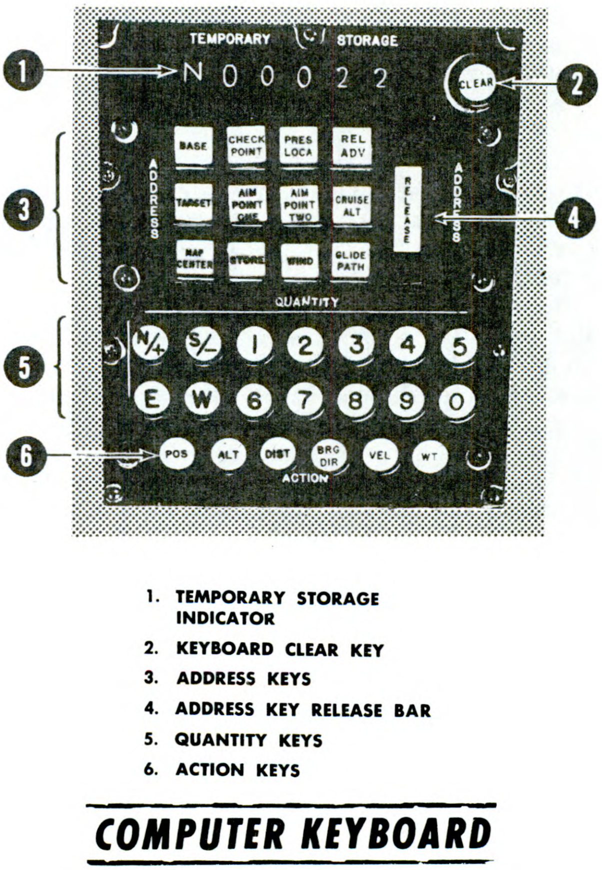

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Figure 11-13. –Keyboard control panel.

KEYBOARD CONTROL PANEL

The keyboard control panel (fig. 11-13) is used by the B/N to insert data relative to the intended mission. The panel consists of the address keys, quantity keys, action keys, clear button, and a temporary storage indicator.

Address Keys

The address keys consist of 12 pushbuttons and a release bar. These instruct the computer to establish quantity data as reference for subsequent application with a particular mission requirement.

NOTE: The address keys are not mechanically interlocked and two may be depressed at a time. Therefore, it is essential that the release bar be actuated after information concerning a given address has been entered.

Once a key has been depressed, it will remain depressed until the release bar is actuated. The function of each of the keys is given in the following paragraphs:

1. BASE—This key is depressed to set in latitude and longitude coordinates during data insertion. Both coordinates are inserted as degrees and minutes, and altitude is inserted as feet.
2. CHECKPOINT—Depressing this key permits the insertions of the checkpoint latitude and longitude coordinates to degrees and minutes, and the altitude of the checkpoint in feet.
3. TARGET—This key is depressed to set in latitude and longitude coordinates during data insertion. Both coordinates are inserted as degree and minutes, and altitude is inserted in feet.
4. AIMPOINT ONE—This key is depressed to insert the location of preselected aimpoint one. The location is inserted with respect to specified coordinates and is programed as a range and bearing offset from preset target or base coordinates. The bearing is addressed in degrees and minutes (360°00') while distance is addressed in feet (99,999'). Aimpoint altitude is entered as differential altitude with respect to the specified coordinate elevation.
5. AIMPOINT TWO—This key is depressed to insert information similar to that outlined in aimpoint one, except that the information inserted is defined with respect to a second preselected aimpoint.

NOTE: Two offset bearings and distances are available for use with either base or target steering modes.

6. PRES LOCA (Present Location)—Depressing this key permits insertion of the latitude and longitude coordinates of the aircraft's present location, and the altitude of the location is also inserted in the computer.
7. CRUISE ALT (Cruise Altitude)—This key is depressed to insert the desired release slant range for STRAIGHT PATH free-fall attacks.
8. MAP CENTER—Presently inoperative.
9. REL ADV (Release advance)—This key permits the B/N to instruct the computer to send a release pulse at a selected distance in advance of the computed release point.
10. STORE (Store Weight)—This key is depressed to program the computer with information regarding the total weight of the stores in pounds.
11. WIND—This key is depressed to insert into the computer the wind velocity and direction. These are inserted in standard form; i.e., true direction in degrees and minutes and velocity in knots.
12. GLIDEPATH—This key is depressed to insert the various data necessary to establish the appropriate landing glidepath—the true bearing of the runway, in degrees and minutes, and the altitude of the glidepath interception point in feet above sea level.
13. RELEASE—This bar is momentarily depressed to release any depressed address key.

Quantity Keys

The quantity keys (fig. 11-13) consists of 14 momentary keys, marked 1, 2, 3, 4, 5, 6, 7, 8, 9, 0, N/+, S/-, E and W. These keys are used to insert the various quantity data with respect to the indicated address keys. The keys are depressed individually. Once the quantity key has been depressed, the corresponding figure will appear in the temporary storage indicator readout window. This provides the B/N with a means of checking to insure that the correct information is being inserted into the computer.

The actual insertion sequence into the computer memory requires that the B/N depress the appropriate address key, insert quantity data by depressing the correct quantity keys, checking the indicated value on the temporary storage indicator, and finally, depressing the related action key to channel the data to the storage area within the computer memory drum.

If, during the keyboard insertion sequence, the B/N accidentally actuates the wrong key or the information is changed, the data appearing on the temporary storage indicator can be erased by depressing the clear button (fig. 11-13). This erases all of the information appearing in the temporary storage indicator.

To insert data into the memory drum of the computer, it will be necessary that a total of six quantity keys be depressed, regardless of the number of significant digits in the basic information. The first key to be depressed will always be one of the N/+, S/-, E, or W keys for position, or the N/+, S/- keys for plus or minus quantities.

NOTE: When the N/+, or S/- key is depressed, the temporary storage indicator will read N or S only, despite the condition being programed. It will therefore be necessary for the B/N to realize that the appropriate value is being designated, since the + or - signs do not appear in the readout window.

After the key has been depressed denoting the selected position or sign, the quantity can be inserted. If necessary, this is accomplished by prefixing the significant digits with the necessary number of zeros to result in a six-digit insert. For example, if the latitude to be inserted in N 40°05', it will be necessary that the B/N depress the N/+ key; followed by the 0 key, and then the 4, 0, 0, 5, keys. This will provide the necessary six-digit insertion. Failure to depress the necessary six-digits will disable the action button and data cannot be inserted.

NOTE: It will be necessary that the B/N depress and hold the desired quantity key until the appropriate figure appears in the temporary storage indicator.

Action Keys

The six action keys (fig. 11-13) are located below the quantity keys, and are marked POS (position), ALT (altitude), DIST (distance), BRG DIR (bearing direction), VEL (velocity), and WT (weight). After the appropriate quantity keys have been depressed, the B/N inserts the information into the computer memory drum by depressing the related action key. This action simultaneously clears the temporary storage indicator for additional information insert. The action keys function to program the computer for the information storage as indicated in the following paragraphs:

1. POS (Position)–When this key is depressed, the computer is advised to store the information presented on the temporary storage indicator on the appropriate position track in in the memory drum. This information will include the longitude, and latitude of the base, target, present location, or checkpoint.

2. ALT (Altitude)–When this key is depressed, the computer is advised to transfer the information in the temporary storage indicator to the memory drum related to the altitude of the base, target, present location, glidepath, checkpoint, or aimpoint, and the desired release slant range for straight path attack.

3. DIST (Distance)–When this key is depressed, it instructs the computer to store the information appearing in the temporary storage indicator regarding the distance to the aimpoint (aimpoints one and two) from the target.

4. BRG DIR (Bearing Direction)–This key advises the computer to transfer the information appearing in the temporary storage indicator to the memory drum of the computer. This information includes the true bearing from the target to the aimpoint. This control also provides a means of supplying the computer with the necessary information regarding the direction of the wind, and the orientation of the landing runway (glidepath).

5. VEL (Velocity)–This key advises the computer to transfer to storage the information regarding the wind velocity indicated on the temporary storage indicator.

6. WT (Weight)–This key instructs the computer to transfer from the temporary storage indicator information on the aircraft weight, relative to the fuel reserve requirements, and the total weight of the stores on board the aircraft.

Temporary Storage Indicator

The temporary storage indicator (fig. 11-13) consists of a digit counter. The reading on the indicator is controlled by the selection of the quantity keys during the insertion sequence. The counter displays a five-digit number, prefixed by a control letter designator representing direction, or a plus or minus value. During all insertion sequences, the B/N will continually refer to these readouts to insure that the correct data is being inserted into the computer drum.

Clear Button

The clear button is located beside the temporary storage indicator (fig. 11-13) and provides the B/N with a means of erasing all information appearing in the temporary storage window. This control will find application in correcting erroneous data punched on the keyboard. When the clear button is depressed, the entire TSR is removed and the tapes return to blanks; then the corrected data may be inserted.

KEYBOARD DATA INSERTION

For the purpose of this procedure, assume that the mission planning data to be inserted is confined to the base location of the aircraft. Aircraft's present location is:

Latitude 36° 49' North
Longitude 76° 02' West
Altitude 22 feet

Initially, it will be the responsibility of the B/N to resolve this information into an acceptable format for the computer; that is, adding the necessary zeros to complete the insertion requirements.

The procedure is as follows:

1. PRESS LOCA - DEPRESS - Depress PRES LOCA key in address section.
2. Quantity keys - DEPRESS - NO3649-Depress quantity keys in order: N, O, 3, 6, 4, 9.

NOTE: Observe the readout NO3649 on the temporary storage window.

3. Position (POS) key - DEPRESS-Since this is a position category, POS key is depressed in order to insert latitude of the present location into the computer. Observe that the temporary storage reading is erased, and that the readout appears on the navigation control panel in the present position (LAT) window if the DATA/PRES POS/ON CALL is in the PRES POS position.
4. Quantity keys - DEPRESS - W07602-Depress quantity keys in order: W, 0, 7, 6, 0, 2.

NOTE: Observe the reading W07602 on the temporary storage window.

5. Position (POS) key - DEPRESS-The longitude of the present location will be transferred into the computer. Observe that the temporary storage reading is erased, and that the reading appears on the navigation control panel in the present position (LONG) window if the DATA/PRES POS/ON CALL is in the PRES position.
6. Quantity keys - DEPRESS - N00022-Depress quantity keys in order: N, 0, 0, 0, 2, 2.

NOTE: Observe the reading N00022 on the temporary storage window.

7. Altitude (ALT) key - DEPRESS-Since this is an altitude category, altitude of the present location is transferred into the computer, the temporary storage indicator is erased, and the readout appears on the navigation control panel in the present position (ALT) window if the DAT/PRES POS/ON CALL is in the PRES POS position.

The latitude, longitude, and altitude of the present location have now been entered into the memory drum of the computer. The inputs to be entered next into the memory of the computer consist of the following:

1. Latitude and longitude, in degrees and minutes; altitude (MSL), plus or minus in feet, for base, checkpoint, and target.

2. True bearing, in degrees and minutes, from target; distance in feet from target; and differential altitude in feet for aimpoint one, aimpoint two and base aimpoint.

3. True bearing, in degrees and minutes; velocity in knots for predicated or estimated wind.

4. True bearing, in degrees and minutes of runway heading or direction of intended landing.

5. Slant range in feet entered under cruise control altitude quantity key. Used in straight path dive attacks to give pilot (vertical) steering indications.

6. Fuel reserve/release advance - N00000

7. Stores weight in pounds.

COMPUTER ERROR CODES

When not in attack, the computer performs 18 diagnostic tests each iteration, provided the error code switch is at READ in aircraft with the P 7 or P 7A program. Should one of these diagnostic tests be failed, the error lights will be turned on and the applicable code will appear in the number three window of the R H U upper panel. In aircraft with the P 7 or P 7A program, the data select switch must be at C to read the error codes.

The computer diagnostic tests and error codes are as follows:

Code	Function
001	Read and restore core
002	Zero + zero
003	C register + B register
004	CT selection
005	CT + RAB_1
006	CT + RAB_{10}
007	C register to B register
008	Absolute value
009	Left shift
010	Multiply
011	Nonaddressed input
012	Time test
013	Core modification
014	RAB_{50}
015	Test VA-VG
016	Double precision multiplication
017	Divide
018	Square root
099	Auto reset
088	Steering cycled with velocity correct switch in MEMORY POINT (P 7A only)

In aircraft with P 7 or P 7A program, if the error code switch is in ERASE, the code 512 is displayed; in attack, no error lights are generated and normal error codes are not displayed. If there is a failure of release valid data (indicated by pathway off on the VDI), the valid data code will be displayed only during the time when the path is off. When the pathway reappears, the code will be erased from the tape dial automatically. The valid data codes are as follows:

Code	Test failed
111	Ballistic solution error, angle to release error or computer iteration time error.
222	True airspeed-inertial error (winds exceed 106 knots + .00325 x altitude in feet).
333	Error in rate of change of elevation velocity vector or integration of normal acceleration.

RELEASE ADVANCE

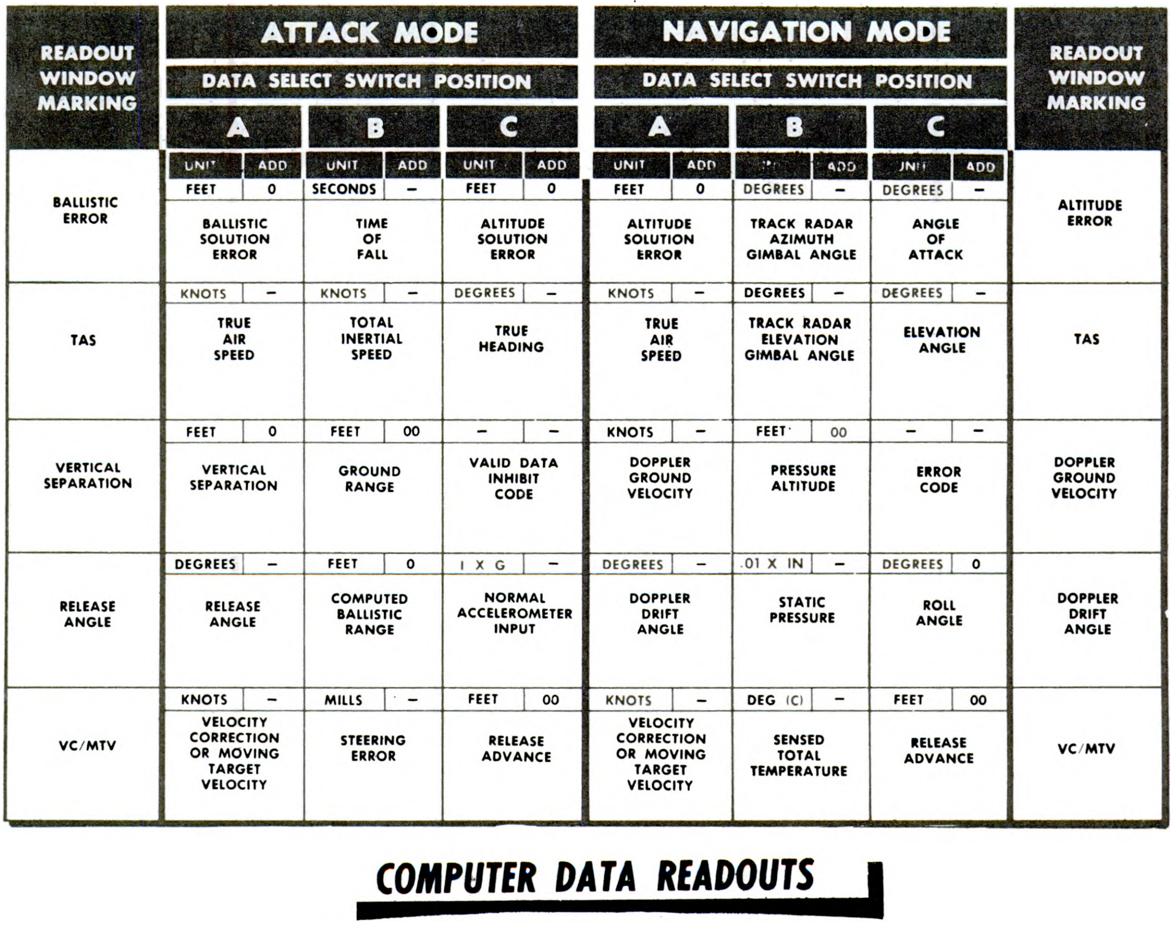
Release advance permits the B/N to introduce a range offset value into the weapon release solution. In this way, by advancing the initial release point a perdetermined distance, the B/N can straddle a target with a train release of bombs. In addition, by advancing or retarding the release point, known system range solution errors can be compensated.

In aircraft incorporating the P 7 or P 7A program, release advance information is inserted by means of the keyboard and is read in the VC/MTV data readout window. The information is introduced into the solution by depressing the release advance button. Depressing the button a second time will remove the information from the solution. The computer can accept keyboard inputs of up to 9999 feet of release advance, and it is displayed in the computer data readout windows to the nearest 100 feet. If the stored release advance information is disturbed in any way while the release advance button is engaged, the light in the button will go off, and the computer will no longer accept the information. To reintroduce the release advance data, it is necessary to disengage the release advance button to remove the data and engage the button to introduce it. Recheck the value in the readout window to be sure that the proper data was entered.

There is a dual channel input for release advance information when it is entered into the computer–one to the computer and the other to the readout. Therefore, it is possible to enter a number into the computer via the FUEL RES address key, have it read correctly in the FUEL RES window, and still have an erroneous value in the computer. It is good procedure to reenter the desired release advance whenever a computer error light or other transient condition occurs. Reentering the desired release advance just prior to the bombing run is also advisable to help insure that the computer is using the correct value.

BALLISTICS COMPUTER DATA READOUTS

Data readouts are displayed to permit evaluation of system operation, malfunction analysis, and reconstruction of weapon release conditions so that weapon impact errors can be analyzed. Figure 11-14 shows the readouts available for the attack case and the navigation case.



READOUT WINDOW MARKING	ATTACK MODE A UNIT	A ADD	A	ATTACK MODE B UNIT	B ADD	B	ATTACK MODE C UNIT	C ADD	C
BALLISTIC ERROR	FEET	0	BALLISTIC SOLUTION ERROR	SECONDS	–	TIME OF FALL	FEET	0	ALTITUDE SOLUTION ERROR
TAS	KNOTS	–	TRUE AIR SPEED	KNOTS	–	TOTAL INERTIAL SPEED	DEGREES	–	TRUE HEADING
VERTICAL SEPARATION	FEET	0	VERTICAL SEPARATION	FEET	00	GROUND RANGE	–	–	VALID DATA INHIBIT CODE
RELEASE ANGLE	DEGREES	–	RELEASE ANGLE	FEET	0	COMPUTED BALLISTIC RANGE	I X G	–	NORMAL ACCELEROMETER INPUT
VC/MTV	KNOTS	–	VELOCITY CORRECTION OR MOVING TARGET VELOCITY	MILLS	–	STEERING ERROR	FEET	00	RELEASE ADVANCE

NAVIGATION MODE A UNIT	A ADD	A	NAVIGATION MODE B UNIT	B ADD	B	NAVIGATION MODE C UNIT	C ADD	C	READOUT WINDOW MARKING
FEET	0	ALTITUDE SOLUTION ERROR	DEGREES	–	TRACK RADAR AZIMUTH GIMBAL ANGLE	DEGREES	–	ANGLE OF ATTACK	ALTITUDE ERROR
KNOTS	–	TRUE AIR SPEED	DEGREES	–	TRACK RADAR ELEVATION GIMBAL ANGLE	DEGREES	–	ELEVATION ANGLE	TAS
KNOTS	–	DOPPLER GROUND VELOCITY	FEET	00	PRESSURE ALTITUDE	–	–	ERROR CODE	DOPPLER GROUND VELOCITY
DEGREES	–	DOPPLER DRIFT ANGLE	.01 X IN	–	STATIC PRESSURE	DEGREES	0	ROLL ANGLE	DOPPLER DRIFT ANGLE
KNOTS	–	VELOCITY CORRECTION OR MOVING TARGET VELOCITY	DEG (C)	–	SENSED TOTAL TEMPERATURE	FEET	00	RELEASE ADVANCE	VC/MTV

COMPUTER DATA READOUTS

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Figure 11-14.–Computer data readouts.

ATTACK-NAVIGATION PANEL (RHU)

The attack-navigation panel in the right-hand unit (fig. 11-15) contains the ballistics computer data readouts, the switches controlling them, and the release advance button.

Data Readout Windows

The data readout windows display values as shown in figure 11-14. The sign of all lateral data is positive to the right with respect to the reference direction. Roll is positive with right wing down. Aircraft elevation angle and track elevation are positive up with respect to the reference direction. Attack solution error is positive for a long impact, and release advance is positive for a short impact. The release angle output is the angle from horizontal (positive up) in all cases except general or high loft retarded weapons. In these cases the value indicated is the last computed angle to go in the iteration prior to release. Time of fall is the value from release to impact or burst height for bombs, and the value from motor burnout to impact for rockets. A functional description of the values displayed are discussed in the next section.

NAVIGATION READOUTS

The data appearing on the computer readout windows are determined by the position of the DATA SELECT switch. The information presented in each readout window for each position of the DATA SELECT switch (A/B/C) the navigation mode is discussed in the following paragraphs. (See fig. 11-14.)

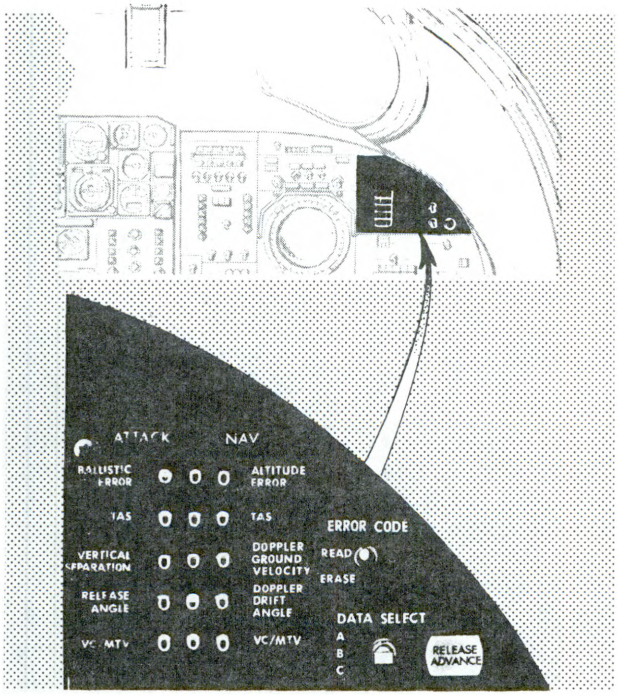

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Figure 11-15. –Attack-navigation panel (RHU).

A. Position

1. Altitude solution error (ALTITUDE ERROR) is a number x 10 representing the difference between the corrected pressure altitude and the inertial altitude. The readout is the smoothed value of this difference. The unsmoothed value is applied directly to the inertial altitude, while the smoothed value is applied to platform vertical velocity. These corrections compensate the long term low drift rates in velocity and altitude. At initial startup of the computer, with the platform in OPER INERL selected and present position data entered, this readout will indicate +200 or -200 if there is an initial vertical velocity error of ±2 feet/second. A positive error in this readout indicates that inertial altitude is above pressure altitude.

2. True airspeed (TAS) is air data computer input Mach converted to RAS in knots.

3. Doppler ground velocity (DOPPLER GROUND VELOCITY) is the direct AN/APN-153 ground speed in knots.

4. Doppler drift angle (DOPPLER DRIFT ANGLE) is the direct AN/APN-153 drift angle in degrees. Right drift is positive; left drift is negative.

5. Velocity correction or moving target velocity (VC/MTV) is displayed in knots. When the velocity correct switch is in MEMORY POINT, velocity correction is displayed. When the AMTI control is ON, target velocity is displayed. When velocity correct and AMTI are both ON, velocity correction is displayed.

B. Position

1. Track radar azimuth gimbal angle is in the azimuth position in degress of the track radar antenna relative to the ADL. Right is positive; left is negative.

2. Track radar elevation gimbal angle is the elevation position in degrees of the track radar antenna relative to the azimuth gimbal. Up is positive; down is negative.

3. Pressure altitude is uncorrected altitude in feet x 100 above the standard datum plane (29.92 inches of mercury).

4. Static pressure is raw static pressure outside the aircraft in inches of mercury to the nearest 0.1 inch.

5. Sensed total temperature is the uncorrected outside air temperature in degrees centigrade.

C. Position

1. Angle of attack is the true aircraft angle of attack in degrees.

2. Elevation angle is aircraft pitch angle in degrees (angle between ADL and horizontal reference).

3. Error code is a number representing one of 18 computer errors.

4. Roll angle is aircraft roll angle in degrees.

5. Release advance is the amount in feet of range offset that has been inserted into the solution. Offsets up to 9999 feet will be indicated to the nearest 100 feet. Values less than 100 feet read zero.

ATTACK READOUTS

With the data select switch in the position shown, the following readouts will appear in the appropriate windows.

A. Position

1. Ballistic solution error (BALLISTIC ERROR) is the difference in feet x 10 between the computed weapon release condition and actual release range.

2. True airspeed (TAS) is the same as that displayed in the navigation readouts.

3. Vertical separation (VERTICAL SEPARATION) is altitude in feet x 10 above the target, and is derived from keyboard inputs or track radar.

4. Release angle (RELEASE ANGLE) is one of the following values:

a. For free-fall loft, the release angle in degrees.

b. For straight path free fall, the aircraft velocity vector in degrees.

c. For retarded bombs, the angle to go to release.

d. For 2.75 FFAR or Zuni rockets, the launch angle in degrees.

e. For Bullpup missiles, the aircraft depression angle in degrees.

5. Velocity correction or moving target velocity (VC/MTV) is the same as that displayed in the navigation readouts.

B. Position

1. Time of fall is computed time of fall of bombs to impact or air burst point, or rocket time of flight after burnout. The time is displayed in seconds.

2. Total inertial speed is total aircraft velocity in space in knots.

3. Ground range is actual ground range from aircraft to target ± release advance in feet x 100.

4. Computed ballistic range is the horizontal weapon travel from the aircraft to the target in feet x 10. The first digit (the 10's of thousands digit) is assumed to be known and is not displayed.

5. Steering error is the azimuth steering error to the release point in mils.

C. Position

1. Altitude solution error is the same as that displayed in the navigation readouts.

2. True heading is displayed in degrees.

3. Valid data inhibit codes are numerical designations of valid data tests. The appearance of these codes (111, 222, or 333) in conjunction with ADI pathway disappearance indicate failure of a valid data test as shown in the following:

Code	
111	Ballistic solution error, angle to release error or computer iteration time error.
222	True airspeed - inertial error (winds exceed 106 knots + 0.00325 x altitude in feet).
333	Error in rate of change of elevation velocity vector or integration of normal accelerometer.

4. Normal accelerometer input is the normal g force exerted on the aircraft in g x 0.1.

5. Release advance is the same as that displayed in the navigation readouts.

ERROR CODE SWITCH

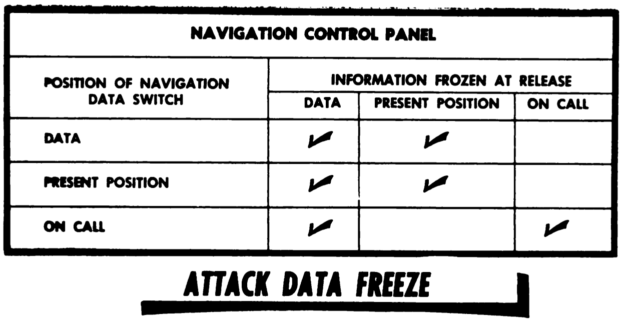
The error code switch (fig. 11-15) is a two-position toggle switch marked READ/ERASE. In the READ position, error codes can be read in the number three window. (The DATA SELECT SWITCH must be in position C to read error codes.) When the switch is placed to ERASE, the error code appearing in the readout window will be erased and the computer error lights will go out. The switch should normally be left in READ.

RELEASE ADVANCE BUTTON

The release advance button is marked RELEASE ADVANCE and is used to enter release advance information into the computer's computations. When the button is engaged and the information is being accepted by the computer, the light in the button is illuminated.

ATTACK DATA FREEZE

When the computer is in an attack condition, all the information available in the right-hand unit attack-navigation panel windows as well as some that is available in the navigation control panel windows are frozen at weapon release. The computer continues to operate normally, but the data in the windows remains unchanged until an action key on the keyboard is depressed. All values in attack-navigation panel windows may be read by moving the data select switch through its three positions. The information that is frozen in the navigation control panel windows depends on the position of the navigation data switch



NAVIGATION CONTROL PANEL			
POSITION OF NAVIGATION DATA SWITCH	INFORMATION FROZEN AT RELEASE		
	DATA	PRESENT POSITION	ON CALL
DATA	✓	✓	
PRESENT POSITION	✓	✓	
ON CALL	✓		✓

ATTACK DATA FREEZE

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Figure 11-16. –Attack data freeze.

(fig. 11-16). When the switch is in PRES POS or DATA at release, present position and data information will be frozen and may be read by making use of the navigation data switch. When the switch is in ON CALL at release, on-call and data information will be frozen.

PROGRAMED MODES

All data processing and control functions of the ballistics computer are governed by its stored internal program. This program is divided into five basic subdivisions as follows: preflight, takeoff, flight, landing, and test. These program subdivisions govern the operation of the ballistics computer in its operating modes, which bear the same titles. The following paragraphs describe the functions and capabilities of the ballistics computer while operating in each of its programed modes.

Preflight Mode

The preflight mode enables operational testing of the ballistics computer prior to takeoff. This mode also allows the B/N to insert strategic navigation and target data (command instructions) into the main memory, through the ballistics computer keyboard and operating controls.

Takeoff Mode

The takeoff mode of the ballistics computer is initiated when the aircraft is alined for takeoff from a base runway or carrier deck. This mode causes the ballistics computer to generate a dead-ahead heading command, which is displayed to the pilot by the analog display indicator. This display is an analog view of the command pathway, ground stabilized to the takeoff heading of the aircraft.

Flight Mode

The flight mode of the ballistics computer is the major operational mode, with respect to navigation and attack computations. There are two basic navigation subdivisions in this mode–present position and direction.

The attack portion of the flight mode program contains four programs–general, straight, hi-loft, and rocket, which are dependent upon computer operation. The functions performed by the ballistics computer, using both the navigation and attack programs of the flight mode, are described in the following paragraphs.

FLIGHT MODE - NAVIGATION (PRESENT POSITION).–Any of the following three modes may be chosen to determine present position, using inputs from the inertial navigation system: inertial, emergency Doppler, and dead reckoning. In the inertial mode, computations are based on both inertial navigation system and radar navigation set quantities. In the emergency Doppler mode, platform corrections are obtained from radar navigation set velocity information. In the dead reckoning mode, platform corrections and velocity computations are obtained from air data computer velocity data, in conjunction with windspeed information manually inserted into the ballistics computer.

FLIGHT MODE - NAVIGATION (DIRECTION).–Navigation computations to determine aircraft direction are controlled by a selected steering or checkpoint mode. These two modes specify the destination of the aircraft and direct the positioning of search radar cursors. When the checkpoint navigation mode is selected, steering functions are uninterrupted and the ballistics computer directs the radar cursors to the navigation checkpoint of previously inserted latitude and longitude. The aircraft may be controlled by the AFCS, or by the pilot, following analog display commands. The AFCS and analog display receive ballistics computer outputs. Radar cursors (range and azimuth) are positioned by the ballistics computer except when manually overridden. There are four basic steering modes which are discussed in the following paragraphs:

1. BASE mode operation instructs the ballistics computer to provide direction signals toward the previously inserted latitude and longitude of the base at which the pilot intends to land. When no offset is indicated, base mode operation positions the radar cursors

toward the landing base. When the B/N inserts offset information into the aft pedestal unit, the radar cursors are directed toward an offset aimpoint, information is inserted as bearing, direction, and differential altitude with respect to either base or target, not as latitude and longitude.

2. PRESET TARGET mode operation instructs the ballistics computer to direct the aircraft toward a target, according to coordinates which have been previously inserted, by means of the keyboard. When no offset is indicated, the radar cursors are directed toward the target. When an offset is indicated, the radar cursors are directed toward an offset aimpoint.

3. OPPORTUNITY TARGET mode operation instructs the ballistics computer to direct the aircraft toward the point represented by the intersection of the radar range and azimuth cursors.

4. NO STEERING mode operation instructs the ballistics computer to suspend steering instructions to the aircraft. Depending upon the radar slew control position, the radar cursors either remain fixed on a ground point or may move at aircraft velocity. The cursors may also remain fixed on a moving ground target.

FLIGHT MODE - ATTACK.—The flight mode normally provides navigation commands to the aircraft subsystems and the crewmembers, unless an attack switch on the slew control, or an uncage switch on the flight stick, is actuated. When either of these switches is operative, the ballistics computer is instructed to modify navigation calculations to obtain attack solutions. The ballistics computer performs different attack programs, as dictated by the type of weapon selected and the attack mode desired. Manually selecting a mode of weapon delivery causes the ballistics computer to perform a program of calculations unique to that particular mode, enabling the ballistics computer to solve weapons delivery equations and generate an appropriate weapon release signal. Computed steering and release commands permit the aircraft to make the most advantageous weapon delivery when the commit attack switch is actuated. Any of the following attack modes may be chosen:

1. GENERAL mode attack computations are normally selected during a bombing attack. The ballistics computer computes bomb release equations for low-loft attack angles unless instructed otherwise.

2. STRAIGHT mode attack computations solve equations for a level dive, or glide approach, generating appropriate steering and release commands.

3. HI-LOFT mode attack calculations are used for problems involving the release of bombs using a high-loft attack angle.

4. ROCKET mode computations solve general attack equations for rocket launches.

5. The LAB IP and lab TGT mode computations provide a backup bombing mode independent of the ballistics computer. Weapons release is initiated by the inertial navigation system at a preset pitch-off (loft) angle. In the LAB IP (inertial point) mode, an intervalometer (timer-counter) provides the correct aircraft pullup time after an initial point has been crossed.

6. In the LAB TGT (target) mode, the loft maneuver is started over the target and an over-the-shoulder weapons release is executed.

Landing Mode

The landing mode presents a pathway on the vertical display indicator group, alined with the landing runway or carrier deck. This pathway display aids the pilot in guiding the aircraft to a safe landing under any weather conditions.

Test Mode

The test mode provides a means of verifying the operational status of the ballistics computer by ground maintenance activities. The tests performed in this mode exercise virtually all circuits and components contained in the six major assemblies by programing them through a series of simulated navigation and attack problems. Successful completion of the test mode program indicates a 90 percent probability that the entire ballistics computer is functioning properly.

SEQUENCE OF OPERATIONS IN PROGRAMMED MODES

The internal program governs the computation and control functions performed by the ballistics computer, according to the mode of operation selected by the B/N. The sequence of operations performed in each programed mode is referred to as an iteration, and may be divided into three sequential steps: The first step of an iteration is always performed by the ballistics computer, regardless of operating mode. The second step of an iteration may be performed in one of two possible ways, depending upon the attack status of the aircraft. The final step of an iteration is performed (like the first step) in all operating modes, regardless of the attack status of the aircraft. The three steps of an iteration are performed in an average mean time of 0.5 second. Subject to variances introduced by operation in different modes, the following sequence of operations constitutes the first step of an iteration:

1. Keyboard-entered input data is examined.
2. Doppler navigation calculations are performed.
3. Flight attitude and environmental data inputs are examined; for example, airspeed, temperature, pressure, etc.
4. Altitude computations are performed.
5. Present position is determined (based on data inputs from inertial navigation system, radar navigation set, or dead reckoning sources).
6. Correction signals for inertial platform (part of inertial navigation system) are generated.
7. Navigation solutions to a selected destination are computed.
8. Display-control and flight-command signals, to guide the aircraft to the selected destination, are generated. Radar cursors are positioned when range to the destination is equal to or less than 150 miles.
9. Terrain clearance computations are performed and necessary avoidance commands are generated.

The second step of an iteration contains the following action when the aircraft is not attacking a target:

1. Display control computations are performed for navigation, takeoff, or landing operations.

When the aircraft is actively attacking a target, the second step in an iteration contains the following actions:

1. Ballistic solutions for delivery of selected stores or special weapons are computed.
2. Aircraft guidance display and control signals are generated to guide the aircraft through the computed attack maneuvers.

The third step in an iteration consists of the distribution of guidance display and subsystem control signals, appropriate to the operating mode, and based upon the computations performed in that mode. These signals instruct the aircraft subsystems to perform certain functions, resulting in the implementation of the computed plan.

FUNCTIONAL DIVISIONS OF BALLISTICS COMPUTER

Although the circuits and components of the ballistics computer are housed in nine separate assemblies, none of these assemblies function as an entity in the computing process. For this reason, the theory discussion and circuit analysis which follow describe the ballistics computer as an integrated equipment, divided into five functional units. These functional units comprise circuits and components located throughout the nine major assemblies, and are referred to according to the functions which they contribute to the overall operation of the ballistics computer. The functional units are memory drum unit, control unit, arithmetic unit, input unit, and output unit. (See fig. 11-17.)

MEMORY DRUM

The memory drum unit of the computer comprises a nickel-cobalt plated magnetic drum, and associated circuits and components. The drum contains 160 magnetic recording tracks, each track capable of containing 150 20-bit words (3,000 bits), on which the internal program, timing signals, and other operating data are stored. The memory drum uses 21 read heads, 18 write heads (used only on buffer tracks), 147 read/write heads and 2 space (1 read, 1 write) heads. Temporary storage tracks (buffers) provided on the drum allow for short term storage of sensed strategic data and keyboard inserted commands until such data is needed for specific computations. One reason these buffers are necessary is because the input and output units cannot keep up with the arithmetic unit. The electronic circuits associated with the drum, participate in recording, readout, and distribution of the stored data.

Track Assignment

TIMING TRACKS.–Track No. 1 of the magnetic memory drum is the clock track. Track No. 3 is the word marker/origin pulse track. The clock track contains a 200-kHz clock signal. This signal is read, amplified, and sent to several clock pulse generators distributed

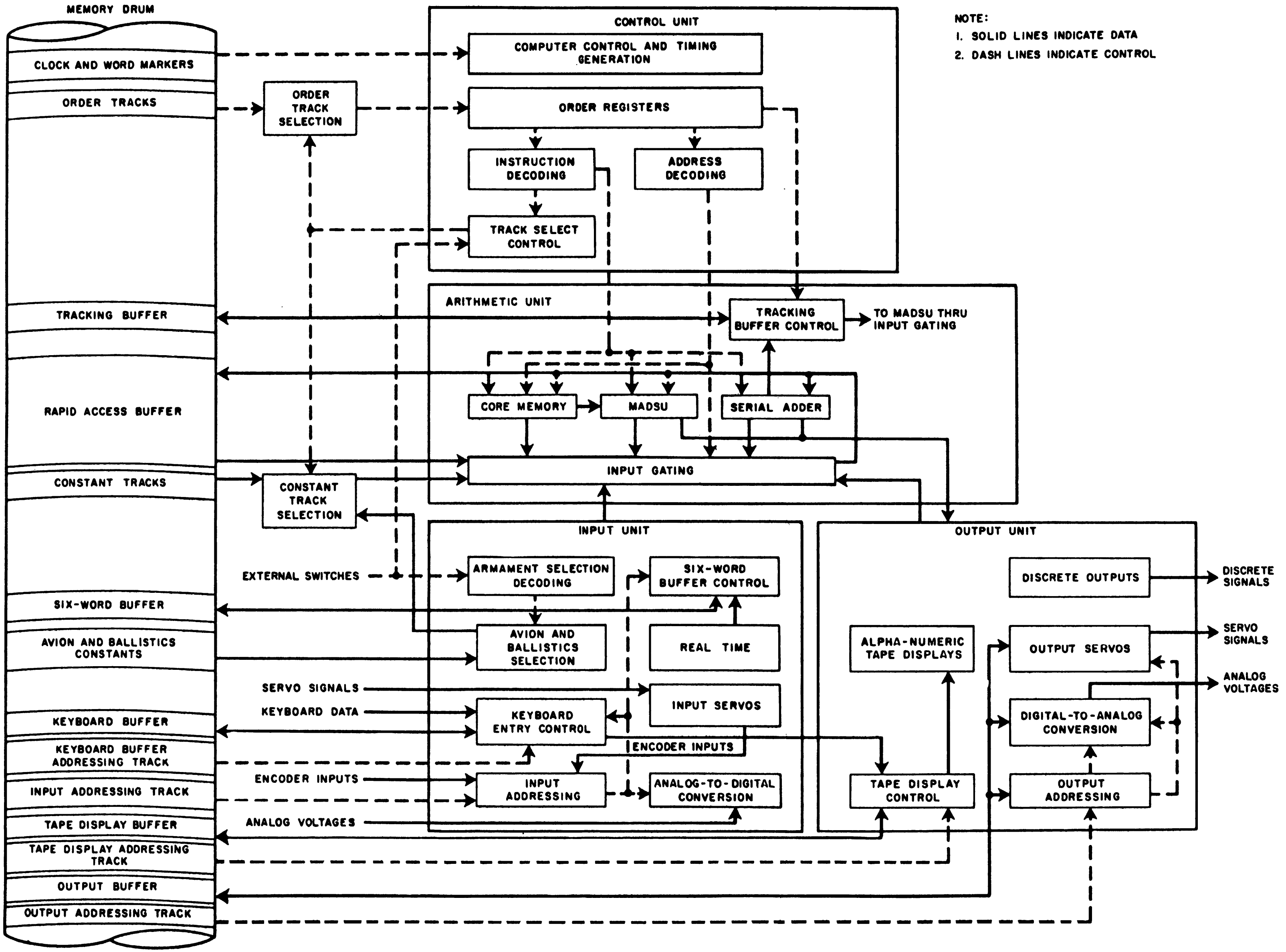

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Figure 11-17. -Ballistics Computer Set AN/ASQ-61A, functional block diagram.

throughout the computer. The word marker/origin pulse track contains word marker signals that occur each word-time and the origin pulse that occurs each 150 word-times.

ORDER TRACKS.–Order tracks permanently store instructions, addresses, and markers on 112 memory drum tracks. These tracks are divided into 56 channels of two tracks each. These two tracks are addressed simultaneously although the functions each perform are different. To distinguish between these two tracks, one track in each channel is called the A-word order track and the other track is the B-word order track. Read heads are selected in pairs by instruction track selectors in the control unit. Instruction words are serially read into read amplifiers and then sent to the order registers. The A-word data contains arithmetic unit addresses and instruction, constant-track jump instructions and addresses, and discrete output and special instructions. The B-word data contains addresses for the rapid access buffer in addition to core memory and order track jump instructions and addresses. Tracking buffer, binary-to-BCD (binary-coded-decimal), and BCD-to-binary markers are located on the B-order word.

CONSTANT TRACKS.–Numerical constants are permanently stored on memory drum constant tracks, 32 of which are used in the arithmetic unit. Ballistic constants use nine tracks and are selected by external switches.

BUFFER TRACKS.–Nine tracks are used for buffers. They are the tape display, keyboard, ballistic constant, digital-to-analog output, rapid access, and tracking buffers.

Word Structure

Each computer word is divided by clock pulse and timing circuits into 20 5-microsecond bit times (BT). The drum, rotating at 4,000 rpm, fixes word time at 100 μ sec. Computer words are read from the drum and transferred throughout the computer, least significant bit (LSB) first. Instructions recorded on A-word and B-word order tracks may contain up to 20 bits of information. Numerical quantities are represented by fractional, 18-bit binary numbers in conjunction with a sign-bit. The binary numbers are contained in bits 1 through 18, with the least significant digit (LSD) in bit position 1 and the most significant digit (MSD) in bit position 18. The sign-bit is located in bit position 19. Positive numbers are represented by a ZERO in bit 19 and the value of the fractional binary number is represented in straight binary form. Negative numbers are represented by a 1 in bit 19 and the value of the fractional binary number is in the TWO's complement form. Binary numbers in the ballistics computer thus may range from -1 (binary 1.000000000000000000) to approximately 0.9999962 (binary 0.111111111111111111).

CONTROL UNIT

The control unit directs all internal operations of the ballistics computer by coordinating the actions of the other functional units. Included in this functional unit are the order register, timing signal generating circuits, and decoding gates for instructions and addresses. The control unit, using basic timing signals and orders received from the memory drum, synchronizes and identifies computer operations. Orders and instructions from selected drum tracks are stored in order registers and decoded into instructions and addresses. These instructions specify the type of operations to be performed by the arithmetic unit, control the selection of the memory drum tracks, from which subsequent orders and arithmetic unit constants are to be obtained, and control a tracking buffer. Decoded addresses control the transfer of data into, out of, and within the arithmetic unit.

Computer Timing

As previously mentioned a 200-kHz clock signal is permanently stored on one of the tracks of the memory drum. To generate the clock pulses, track number one is read by read head RW01 (fig. 11-18). This 200-kHz sine wave is then applied to the read amplifier RA which amplifies and converts the signal to a 3-volt square wave. The two outputs of the amplifier are referred to as RA01 and $\overline{\text{RA01}}$ which are identical, except that the are 180° out of phase with each other.

The output RA01 is now applied to a noninverting amplifier (NIA) for power amplification and then, as NRA1, is distributed to the master clock pulse generators MCP. There are six such generators (PM01 through PM06) only one of which is shown. These generators produce clock pulses every 5 μ sec. The output indicated as PM02 is amplified by logical pulse amplifier (LPA) and in this instance is shown as full clock pulse PC03. It must be understood that the

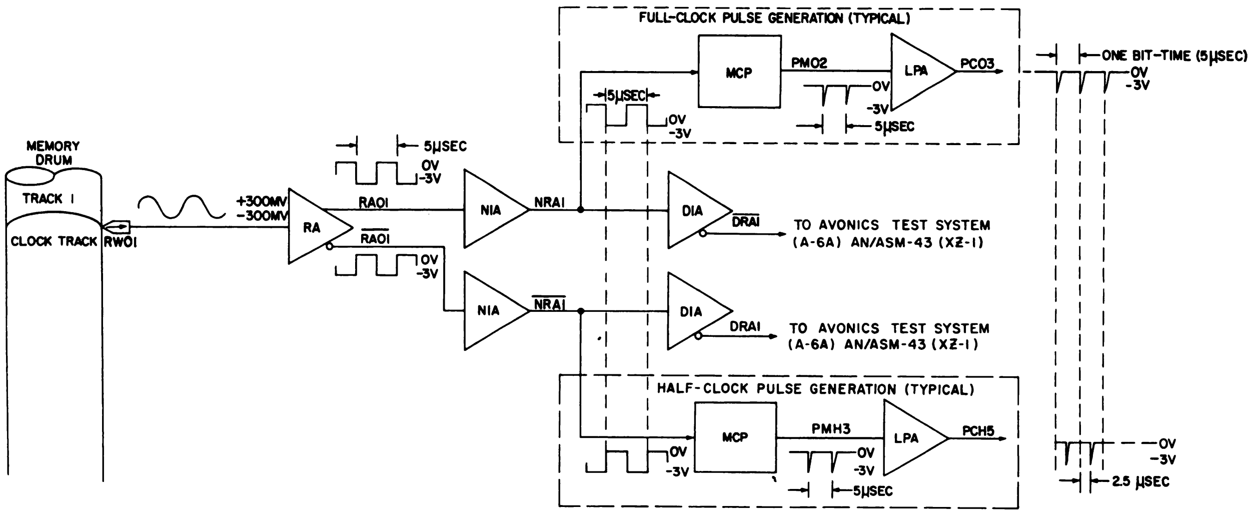

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Figure 11-18. –Clock pulse generation block diagram.

master clock pulse, shown as PM02, also produces clock pulses other than PC03. This is true of all master clock pulses (PM01 through PM06).

The output NRA1 also goes to dual amplifier ($\overline{\text{DRA1}}$) whose output DRA1 is used for test purposes.

Referring again to the diagram note that the output $\overline{\text{RA01}}$ is applied to a noninverting amplifier which produces the signal $\overline{\text{NRA1}}$ that is distributed to the half-clock pulse generators. There are three generators which generate half-clock pulses PMH1 through PMH3. Each half-clock pulse generator also produces clock pulses every 5 µsec but they are displaced 2.5 µsec from the full-clock pulses.

Outputs from the master clock pulse generators and half-clock pulse generators are distributed throughout the computer to various logical pulse amplifiers and flip-flops.

The signal $\overline{\text{NRA1}}$ is also applied to a dual inverting amplifier to produce the output DRA1, which is used for test purposes.

Recording

Information is written on the memory drum by passing a current through a selected write head winding. Flux lines developed by this winding magnetize the drum surface directly beneath the writing head. During each drum revolution as a point on the drum surface that has been magnetized passes under a read head, a voltage representing the stored information is induced in the read head winding.

This process of recording a 0 or a 1 on a magnetic medium appears straightforward enough, and actually is; but the techniques used vary considerably from those used for the more familiar tape recording of speech. The two opposing problems are to obtain the highest packing density and to maintain reliability. To obtain a reasonably high packing density, it is obvious that some distortion can be tolerated. In fact, there is certainly nothing magic in the ability of a pulse with square corners to represent a 1 or a 0 better than a rounded waveform with the desired characteristics.

To record digital data information efficiently, a saturation amplitude signal is normally employed. This results in a memory output signal which is a gross distortion of the pulse being recorded. Actually the signal which is read back is essentially the derivative of the pulse which was read in, or recorded. This is true because, when the magnetic medium is saturated, the output winding "sees" no change in flux and therefore produces no signal. The only time a signal is produced, then, is when going into or coming out of saturation. No change of output level will occur when the level of succeeding digits remains the same (two successive 1's, for instance). This means that no read back signal would appear at this time. With a long series of 1's, it becomes apparent that timing pulses are a necessity; otherwise counting the time intervals would become very difficult.

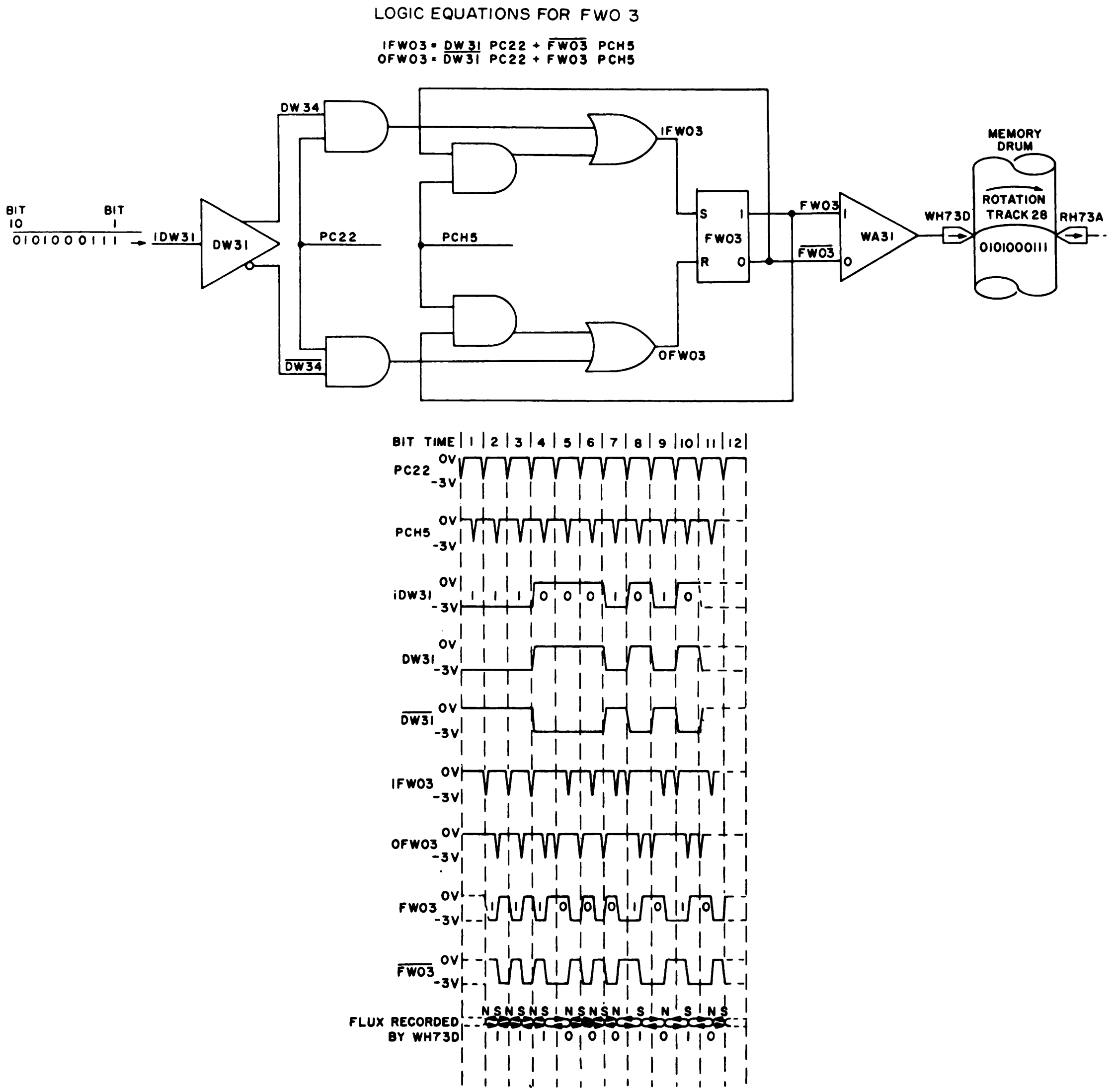

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Figure 11-19.–Manchester recording, timing diagram.

The system used in the ballistics computer to record on the magnetic drum is called the Manchester system and is described in the following paragraphs.

MANCHESTER RECORDING SYSTEM.–The Manchester recording system enables long series of ones or zeros to be recorded on the memory drum magnetic surface by providing a flux change each bit time. Information is stored on the drum surface so that the readback voltage induced in a read head is of one polarity to represent a zero and of the opposite polarity to represent a one. The voltage induced in the read head is proportional to the rate of change of flux, $d\phi/dt$. The drum surface is saturated in one direction during the first half of a bit and in the opposite direction during the second half to write either a one or a zero. The direction chosen for saturating the drum surface on the first half of the bit is determined by the data to be recorded. Flux changes between the two halves is of one polarity for a one and of the opposite polarity for a zero. (See fig. 11-19). Note that when the write flip-flop FW03 output changes state at each half-clock pulse, a discrete bit is coded

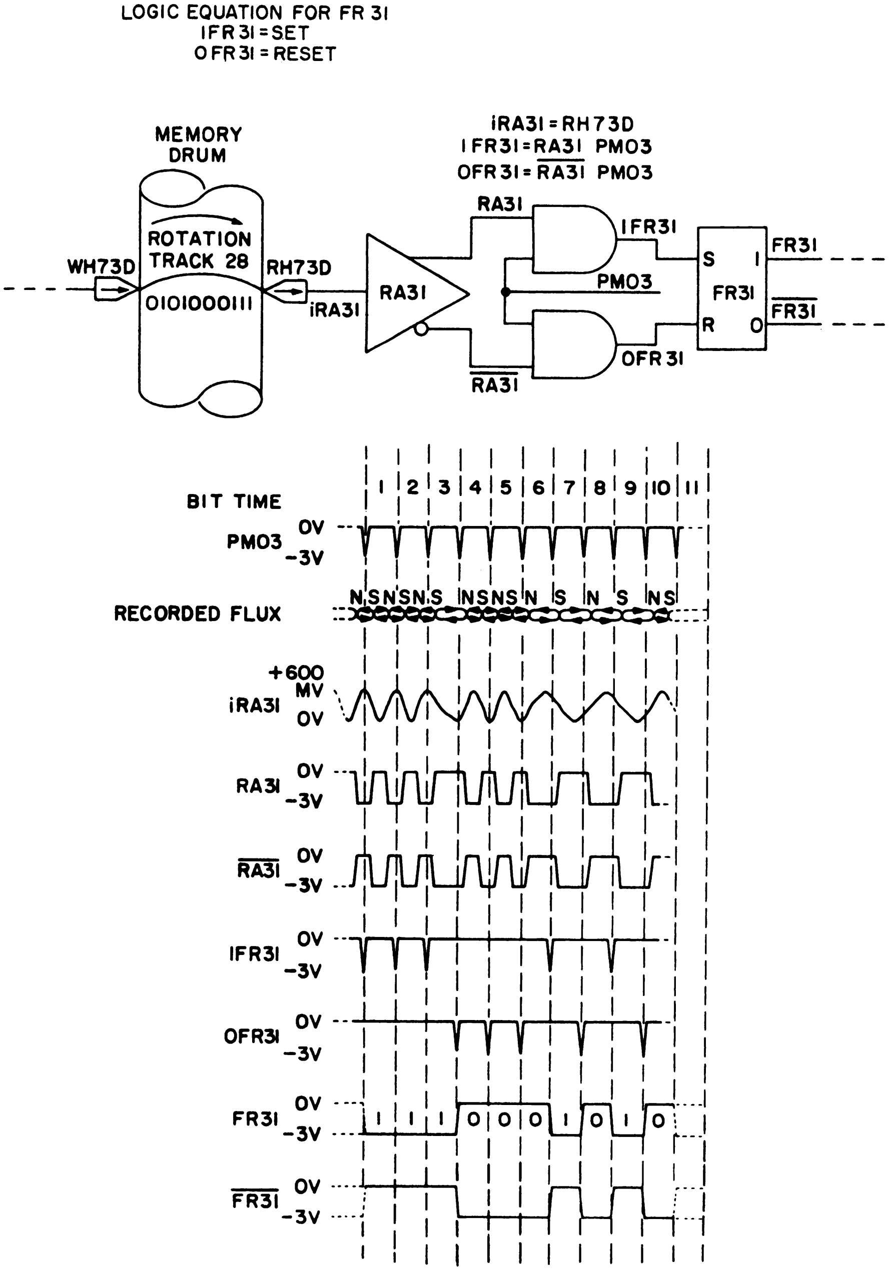

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Figure 11-20. -Manchester reading, timing diagram.

as a true-going or false-going change of state. The write current follows the write flip-flop waveform. A one is recorded by sending current through the head in one direction for the first half of a bit time and in the opposite direction during the second half of the bit time. A zero is recorded in the same manner, except the phase is shifted 180°. When the number to be written on the drum is a series of ones or zeros, the Manchester logic shifts one-half bit time and alternates between zero and one at the half-clock rate. When the number to be written alternates (1010----), the Manchester logic shifts one-half bit time and alternates between one and zero at the full-clock rate.

Information to be written on the memory drum may be amplified by a dual inverting amplifier and then converted to Manchester logic and applied to a write flip-flop. This causes the information to shift once each half-clock time. The write flip-flop output is amplified by a write amplifier and applied to the associated write head.

Information is read from the memory drum by a read head as shown in fig. 11-20. Note that the read head input to the read head amplifier appears as a sine wave for successive ones or zeros with a phase shift marking a change from one to zero or from zero to one. The read amplifier converts the sine wave to a square wave. Manchester logic is shifted one-half bit time and converted to normal logic by a read flip-flop.

ARITHMETIC UNIT

Operating under the direction of the control unit, the arithmetic unit performs all mathematical operations necessary to solve equations programed on memory drum order tracks. The unit is functionally divided into a core memory; a serial adder (SA); a multiply, absolute-value, divide, square root unit (MADSU); and a rapid access buffer (RAB). Input gating circuits, controlled by order register addresses, route data into and out of these functional subdivisions.

The core memory provides a random access facility for storing initial, intermediate, and final arithmetic unit results. (Core characteristics and description are given later in this chapter.) Core instructions specify the insertion and removal of core memory data and addresses specify where these data are to be stored or obtained. Core memory inputs and outputs are controlled by B-order register instruction (03). Constants stored on the drum may also be stored in the core memory, or the output of the core memory may also be recirculated back into the core input.

Communication between the core memory and the computer is provided by the C register, which acts as a buffer. The core memory is composed of ferrite cores, wired in a matrix of 128 columns of 19 cores each; thus it is capable of storing 128 words, any one of which is available through the C register in one word-time. The C register is capable of transferring data, in parallel operation, between the core matrix and the A register of the arithmetic unit; and of transferring data serially between the memory drum and the other elements of the arithmetic unit. Read out from the core memory is always destructive; however, information can be reinserted as it is read out.

The MADSU elements, governed by control unit instructions, perform arithmetic operations on selected drum constants and on data received from the core memory, input unit, RAB, SA, output buffer, constant track, and tracking buffer.

Order register addresses route MADSU data to the output unit, core memory, SA, or RAB, or back into the MADSU.

The SA performs binary addition or subtraction according to order register instructions and receives data from the RAB, constant tracks, input unit, core memory, MADSU section, and the output buffer. The results of an addition or subtraction operation, gated in accordance with control unit addresses, are delivered to the RAB, MADSU, tracking buffer, and core memory in one word-time. Serial adder outputs are also available to the output unit through the output buffer, under the control of programed order register addresses.

The rapid access buffer is a temporary storage facility used to hold data during arithmetic operations. The RAB uses one track of the memory drum for temporary storage of up to 128 words, available 1, 10, or 50 word-times after recording. Unlike the core memory, RAB data are stored in the sequence of insertion and cannot be retrieved at random. The RAB receives inputs from its own outputs as well as from selected constant tracks, the MADSU, SA, input unit and core memory. The RAB inputs are selected by input gating circuits controlled by order register addresses. These addresses also gate RAB outputs to the core memory, MADSU, and SA. Programed, fixed data stored on memory drum constant tracks are gated to all portions of the arithmetic unit by control unit addresses. The position of the drum when the selected track is gated to the arithmetic unit determines the constant obtained.

Core Characteristics

Ferrite cores used in the core memory are magnetically bistable; that is, the cores may be magnetized in either direction. This is accomplished by reversing the direction of the current in a wire passing through the core, which reverses the magnetic state of the core. These characteristics are represented symbolically by a square hysteresis loop. (See fig. 11-21.) Points A and D of this loop represent the maximum magnetization of the core in each state. As indicated, these points are designated 0 and 1. When current is present in the core winding, maximum magnetization is achieved. When current is not applied, deteriorization occurs, leaving the core magnetization at a level represented by point B or E. The nearly square shape of the loop indicates that a specific current level is required to switch the core. Too small a current does not drive the core magnetization level through points C or F. Once the full select current is applied, the core rapidly changes state from C to D or from F to A. Reading the state of a core is a destructive process. The core is driven to the 0 state and the flux change is sensed. When the core is in the 1 state, it is switched from E through F to A. Changing state from F to A causes a maximum current to be induced in the sense winding. This current, indicating the core was in the 1 state, is amplified and sets the respective C register flip-flop. When a core is in the 0 state, it is driven from B to A, which does not induce a current in the sense winding. This lack of current is sensed and used to reset the respective C register flip-flop. Whatever the state of a core before being read, it is always 0 after being read, thus destroying the data in memory and placing it in the C register.

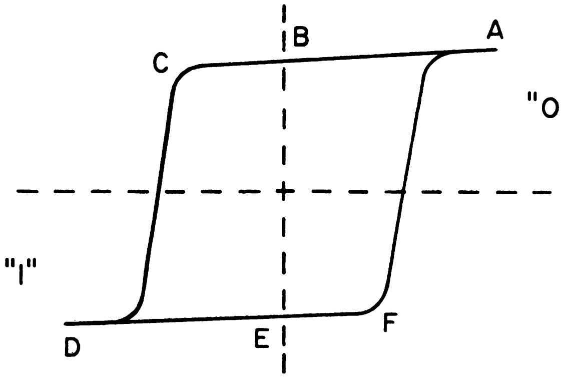

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Figure 11-21.—Ferrite core hysteresis loop.

To mechanize the bistable properties of ferrite cores for a memory device, four windings are placed on each core. (See fig. 11-22.) These are the read, write, information, and sense windings. The read and write currents are of the same value. The read winding has three turns and, when energized, produces a full-select field which switches the core to its zero state. The write winding has two turns wound in opposition to the read winding and produces two-thirds of the full-select field when energized, which switches the core to the one state. The information winding has two turns and carries one-half of the read and write current, producing one-third of the full-select field in a direction dependent on the data to be stored. When a one is to be stored, the information current is driven in the same direction as the write current, producing a full-select field. When a zero is to be stored, the information current is driven in the direction opposite to the write current. This opposition current reduces the two-thirds write field to one-third of the full-select field, a value insufficient to switch the core.

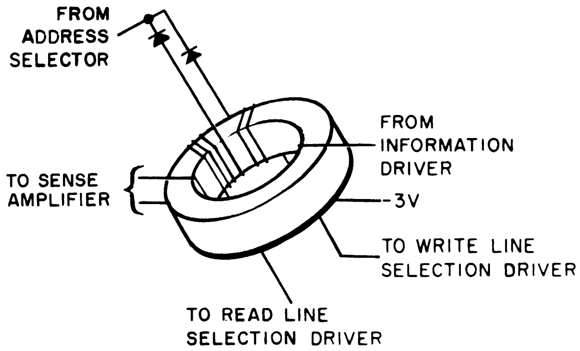

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Figure 11-22.—Ferrite core windings.

To use the cores as a memory device, they are wired in a matrix of 128 columns of 19 cores. The 19 cores hold the 19 bits that represent a word. The information and sense windings pass through one core of each of the 128 columns, thus controlling the information and sensing of a specific bit of any word. The address selectors specify one of the 16 groups of 8 columns that contains the word being operated upon. The column that contains the word is selected by the line selection drivers. Sixteen specific columns are selected by the line selection drivers, but only the one column that is controlled by the selected address selector is activated by either the write line selection driver or the read line selection driver, depending on the operation being performed.

Information to be stored in the core memory is transferred in parallel from 19 C register flip-flops to the cores through 19 information drivers. The information drivers energize the information lines of the 19 rows corresponding to the register flip-flops. The storage of the data requires a write pulse which is gated by the write line select drivers. The selected column is the only one of the 128 that is affected by the information lines.

Reading of information is a similar operation to writing. Selection is accomplished as in writing, except that a read pulse is applied to the read line select drivers. The read line select drivers switch the 19 cores in the selected column to zero. Switching of the cores induces a current in the sense windings that is amplified by sense amplifiers. The sense amplifiers then set or reset the register flip-flops according to the state of the corresponding cores.

A SAMPLE ARITHMETIC UNIT

The primary function of the arithmetic unit as previously mentioned is to perform the mathematical operations dictated by the program. These operations are usually programed utilizing methods that allow them to be manipulated arithmetically. The distinguishing characteristic of arithmetic operations lies in the fact that numerical quantities form the elements of the calculation. The arithmetic unit also performs operations that are not usually considered to be arithmetic, such as comparing numbers, shifting right or shifting left.

Digital computers are usually designed to perform all operations by modifications of the addition process. The following paragraphs describe the basic requirements of an arithmetic unit and develop the logic necessary for its primary operations. The arithmetic unit described performs all of its operations by addition.

The requirements of an arithmetic unit are described with reference to the block diagram in fig. 11-23. The unit shown is capable of adding, subtracting, and multiplying. The number of additional elements that would be required for division make it impractical to show the divide operation. However, the requirements for division are discussed, making it fairly easy to visualize what additional components would be necessary to perform the operation. The mathematical theory of square root operation is also given.

The block diagram shows a four-bit parallel adder, five registers, a complementing network, an overflow detector, a cycle counter, a timing pulse generator, and a control network. The timing generator is not a physical part of the arithmetic unit; it is included here to help clarify the way that a sequence of steps required to perform an arithmetic operation is controlled.

Adders

The adders used in this unit are full adders of the type discussed in chapter 14 of Aviation Fire Control Technician 3 & 2, NavPers 10387. Each adder is designed to accept the addend, augend, and a carry from the previous order to produce a sum and a carry output.

Registers

The registers contain all the information necessary for a given arithmetic operation and for storing the result of the operation. The unit shown uses five registers: the M, A, B, C, and D registers. All information taken from the memory passes through the M, or main, register. The M, A, and B registers are used for the add and subtract operations; multiplication operations use all five registers. The transfer gates used to convey information from one register to another are not shown on the diagram since they do not directly affect the logic. Registers are discussed in detail in chapter 14 of Aviation Fire Control Technician 3 & 2.

Complementing Network

A number is applied to the adder in either its true of its complemented form, depending upon the arithmetic operation being performed. Figure 11-24 shows a simple complementing network. In a sophisticated complementing register one network is needed for each bit in the word.

The circuit consists of two AND gates and an OR gate. The true and complement inputs

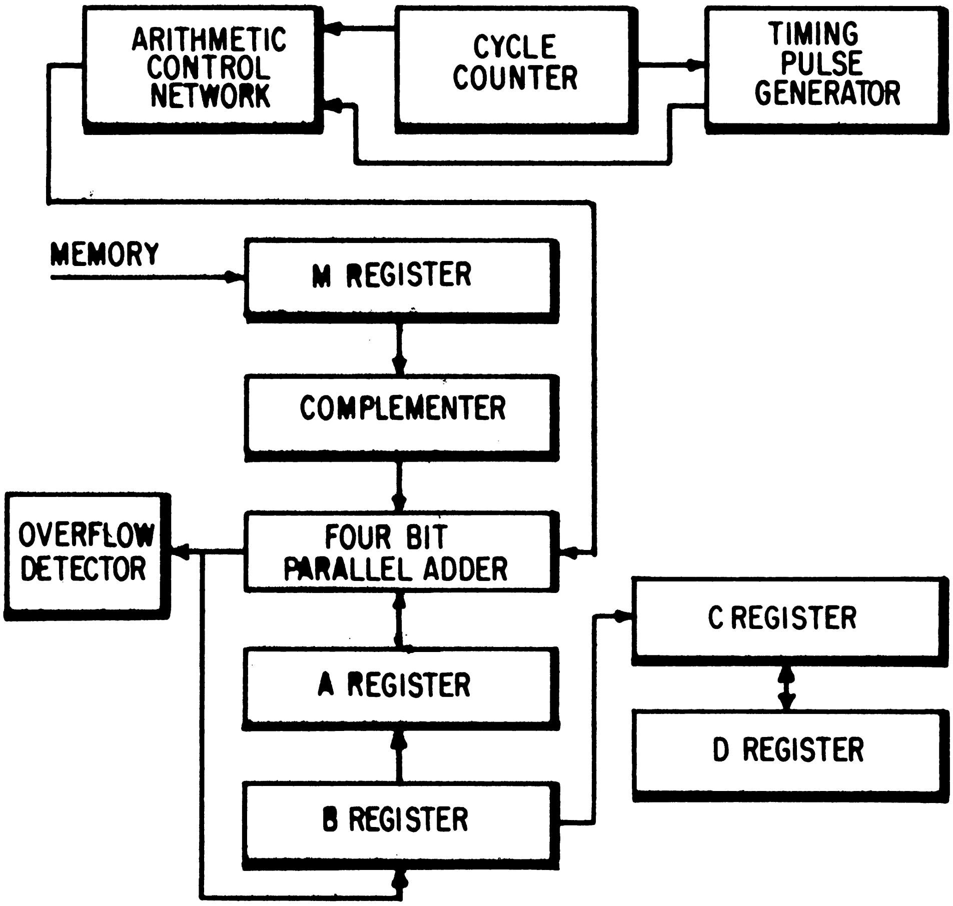

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Figure 11-23. –Sample arithmetic unit block diagram.

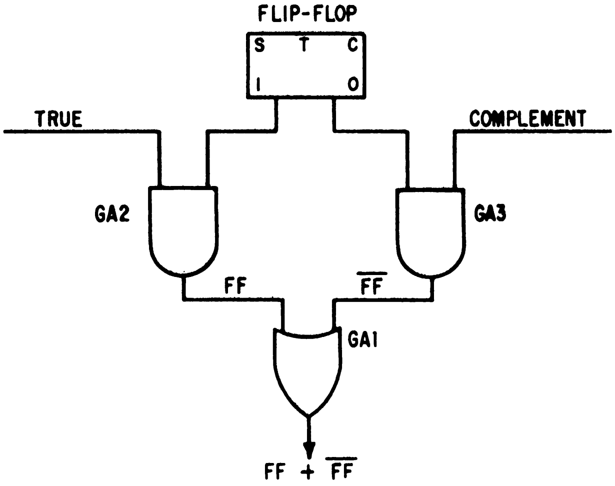

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Figure 11-24. –Complementing network.

determine whether or not the information bit contained in the flip-flop will be complemented. A true input applied to GA2 will allow an output of 1 from the complementer if the flip-flop is in the one state. If the flip-flop is in the zero state when the complement input is present, there will be an output from GA3, indicating a binary one. The conditions for a true or a complement input are determined by the control gates for the operation being performed.

Overflow Detector

The overflow detector provides an indication when the result of an arithmetic operation exceeds the word length the unit is capable of handling. The word length of this sample unit is four bits. If the sum of two numbers has more than four bits, the overflow detector will provide an output which can be used to give and alarm or stop a sequence of operations. The logical operation of the overflow detector when addition and subtraction are performed by the sample unit will be discussed.

Cycle Counter

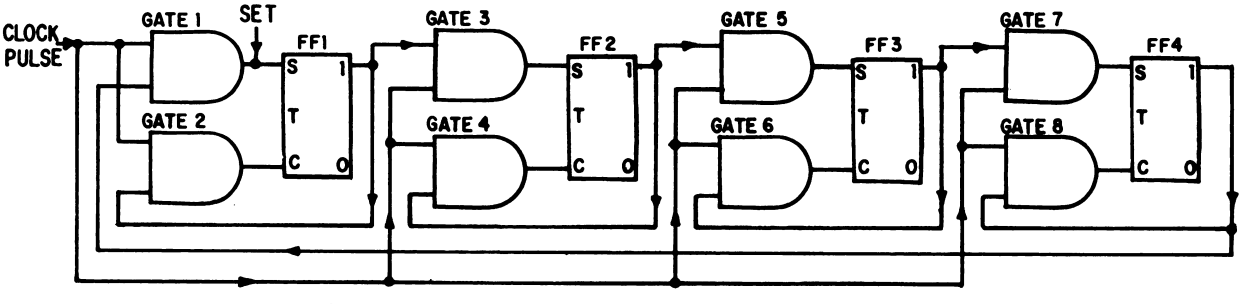
Multiplication and division can be accomplished by a sequence of additions. Each step in the sequence is called an iteration, and the cycle counter keeps track of the number of iterations. In the unit shown, the cycle counter is a down counter. At the beginning of the multiplication operation, the counter is set to the number of add cycles required to complete the operation. At the completion of each add cycle, the count in the counter is reduced by one. Decoded outputs are taken from the counter and applied to control gates so that a completed operation will be indicated. Other gates are controlled by the cycle counter during the multiply operation (as will be seen in the discussion of the logic).

Timing Pulse Generator

The timing pulses for this sample arithmetic unit are generated by a ring counter synchronized with the basic timing of the computer. The counter initiates the transfer shift, clear, and other necessary commands in a definite order so that the desired arithmetic operation is performed. A ring counter is useful here because the counter generates only one high output at a time from its stages. Each output can initiate a separate operation. A four-stage ring counter is illustrated in fig. 11-25.

The timing chart in fig. 11-25 shows that flip-flops 1, 2, 3, and 4 are set to the one state sequentially. All of the gates shown perform the AND function. Initially FF1 is set to the one state while 2, 3, and 4 are in the zero state. The output from the one side of FF1 is fed back to the zero input gate of FF1 and forwarded to the one input gate of FF2. The first clock pulse through these gates sets FF2 to the one state and resets FF1 to the zero state. The second clock pulse sets FF3 to the one state and resets FF2. The third clock pulse sets FF4 and resets FF3. The one output of FF4 is applied to the one input gate of FF1, so that the fourth clock pulse sets FF1 and resets FF4, completing the cycle.

The timing pulse generator used in the sample unit is shown in fig. 11-26. The counter is a ten-stage device used to generate nine pulses, numbered t1 through t9. The output of the first stage is not used. The design of this device allows the use of either a complete sequence initiated by t1 and terminated by t9 or only the t6 through t9 portion of the sequence. The complete cycle is called a major cycle; the abbreviated count, a minor cycle. The gates controlling the major and minor cycles are shown in fig. 11-26. The output of FF1 is applied to either FF2 or FF7, depending upon whether a major-cycle or a minor-cycle control pulse is present. If the output of FF1 is applied to FF2, the complete count will be generated. If the output of FF1 is applied to FF7, the partial count will be generated. Minor cycles are used for each successive addition or subtraction in multiplication and division operations which do



CP	FF1	FF2	FF3	FF4
0	1	0	0	0
1	0	1	0	0
2	0	0	1	0
3	0	0	0	1
4	1	0	0	0

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Figure 11-25.-Four-stage ring counter and timing chart.

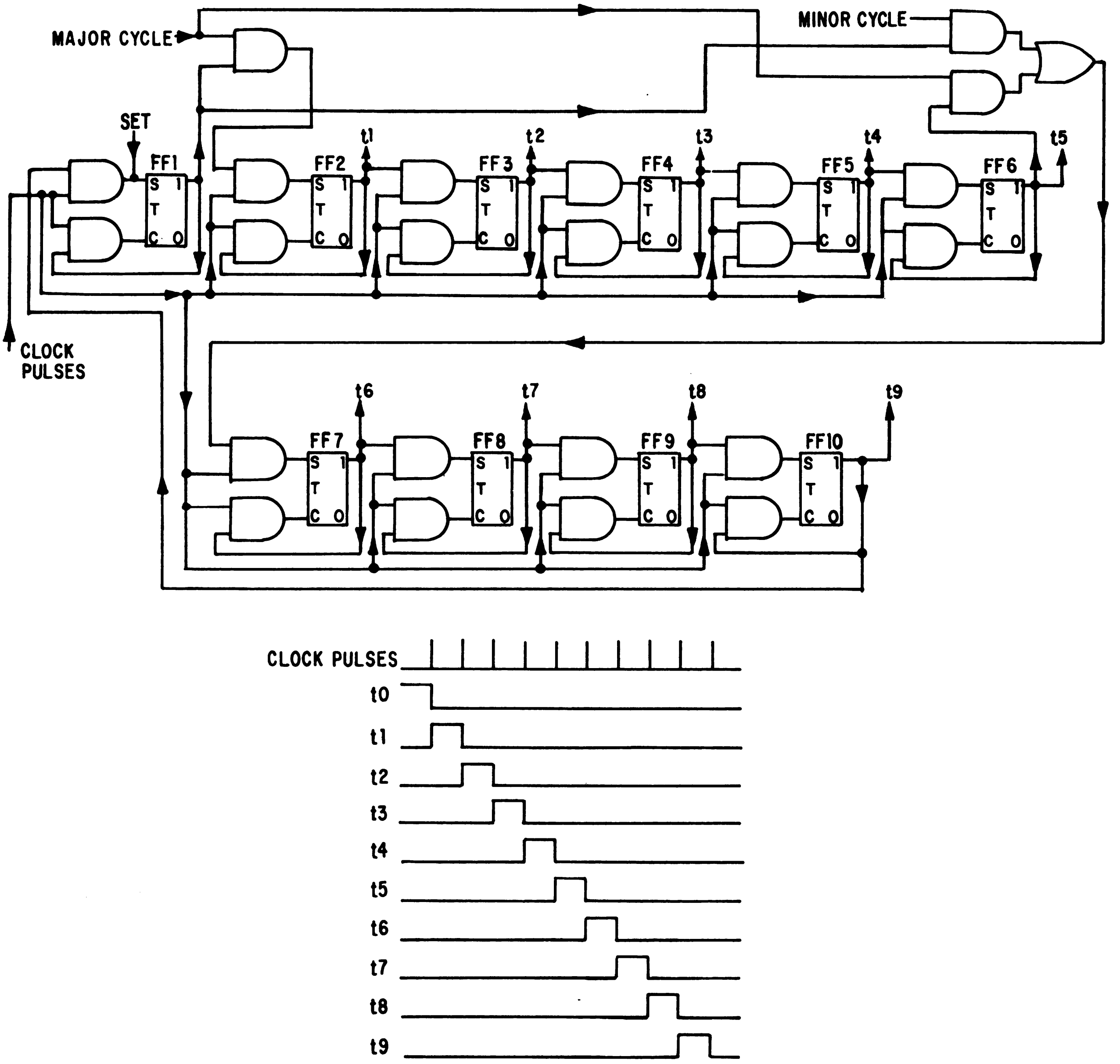

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Figure 11-26. –Timing pulse generator.

not require the complete add or subtract sequence of operation.

Instructions

The sample arithmetic unit has the following four instructions:

1. Transfer-clear.
2. Add.
3. Subtract.
4. Multiply.

Each instruction is generated by the control unit. For the discussion which follows, it will be assumed that the computer is a single address device in which the instruction word consists of the command and the memory location of one number upon which an arithmetic operation is to be performed. Each of the instructions will be explained in terms of both the block diagram and the logic. It is impractical to show all of the gates required for each operation, but the essential gates are shown. As soon as an instruction is given, it is executed automatically in the arithmetic unit by the arithmetic timing pulses.

Transfer-Clear

The purpose of this operation is to extract a number from the memory and place it in the arithmetic unit. Specifically, the number is placed in the A register. If the number is positive, the magnitude bits are transferred to the B register in their true form; if it is negative, the magnitude bits are transferred to the B register complemented. In this computer, the most significant bit of the number is the sign bit. If the sign bit is zero, the number is positive; if the sign bit is one, the number is negative. For example, a plus seven is written 0111; minus seven is written 1111.

The reason for placing the contents in the B register can be seen by referring to fig. 11-23. The two inputs to the adder are the contents of the A register and the contents of the M register applied through the complementing network. The transfer-clear instruction places the first number in the arithmetic unit. When an add, subtract, or multiply instruction is generated, the second number is extracted from the memory and placed in the M register. All operations are done by addition. The contents of the B register are transferred to the A register to become an adder input. The B register is cleared, and the sum or difference is transferred back into the B register. If successive iterations are required, the transfer from the B register to the A register and the placing of the adder contents in the B register are repeated as many times as required.

In order to follow the logic of the operational steps, refer to fig. 11-27. The transfer-clear instruction is essentially an add operation. No other number is in the arithmetic unit at this time; hence the number extracted from the memory is added to 0000, and the sum is placed in the B register. The operational steps are synchronized to the timing pulses shown in fig. 11-26, as follows:

1. At t1 time the transfer-clear level is generated by the control unit. This portion of the operation is not shown. An instruction level is a pulse that remains present for the entire operational sequence. This level is applied to the appropriate gates in the arithmetic unit. They will be pointed out as the explanation progresses.

2. At t2 time the add-subtract flip-flop is set to the zero state. The transfer-clear level is on OR input gate 63. The output of this gate is an input to gate 20. When t2 occurs, AND gate 20 will set the add-subtract flip-flop to the zero state. The t2 pulse is also applied to the zero inputs of all the flip-flops in the M register, clearing it. This logic is not shown in the diagram.

3. At t3 time, a number is extracted from the memory and placed in the M register. The logic for this operation is not shown. The address of the extracted number is a part of the instruction word generated by the control unit. When the number is extracted and placed in the M register, the sign bit is sampled to determine the polarity of the number. If the number is negative, the magnitude bits are complemented. The sign bit is contained in M4, the most significant flip-flop. The one side output of M4 is applied to gate 2 of the complementing unit CM_4 and the zero output is applied to gate 1. If flip-flop M4 is in the zero state, there will be no output from AND gate 1, since the t2 pulse has set the add-subtract flip-flop to the zero state. Consequently there will be no output from gate 9. If M4 is in the one state (representing a negative number), gate 2 will function, allowing an output from gate 9. The output of gate 9 activates gate 61, producing an input to gate 62. Gate 62 drives AND gate 65A. The other input to gate 65A is high for all instructions except multiply since it is driven by an inverter. The output of gate 65A drives gates 3, 5, and 7 plus an inverter. The output of the inverter is applied to gates 4, 6, and 8. Therefore, the true level is generated whenever there is no output from gate 65A. CM_3, CM_2, and CM_1 will follow the information in M3, M2, and M1. If there is an output from gate 65A, the true sides of the complementing stages will be inhibited and the complementing side will be activated. The outputs from CM_3, CM_2, and CM_1 are applied to the adders through gates 15, 16, and 17, which are multiply control gates that are enabled by the mul-div control flip-flop. Pulse t2 sets this flip-flop to the one state. The flip-flop remains in the one state during the add and subtract operations. Because of the presence of the transfer-clear

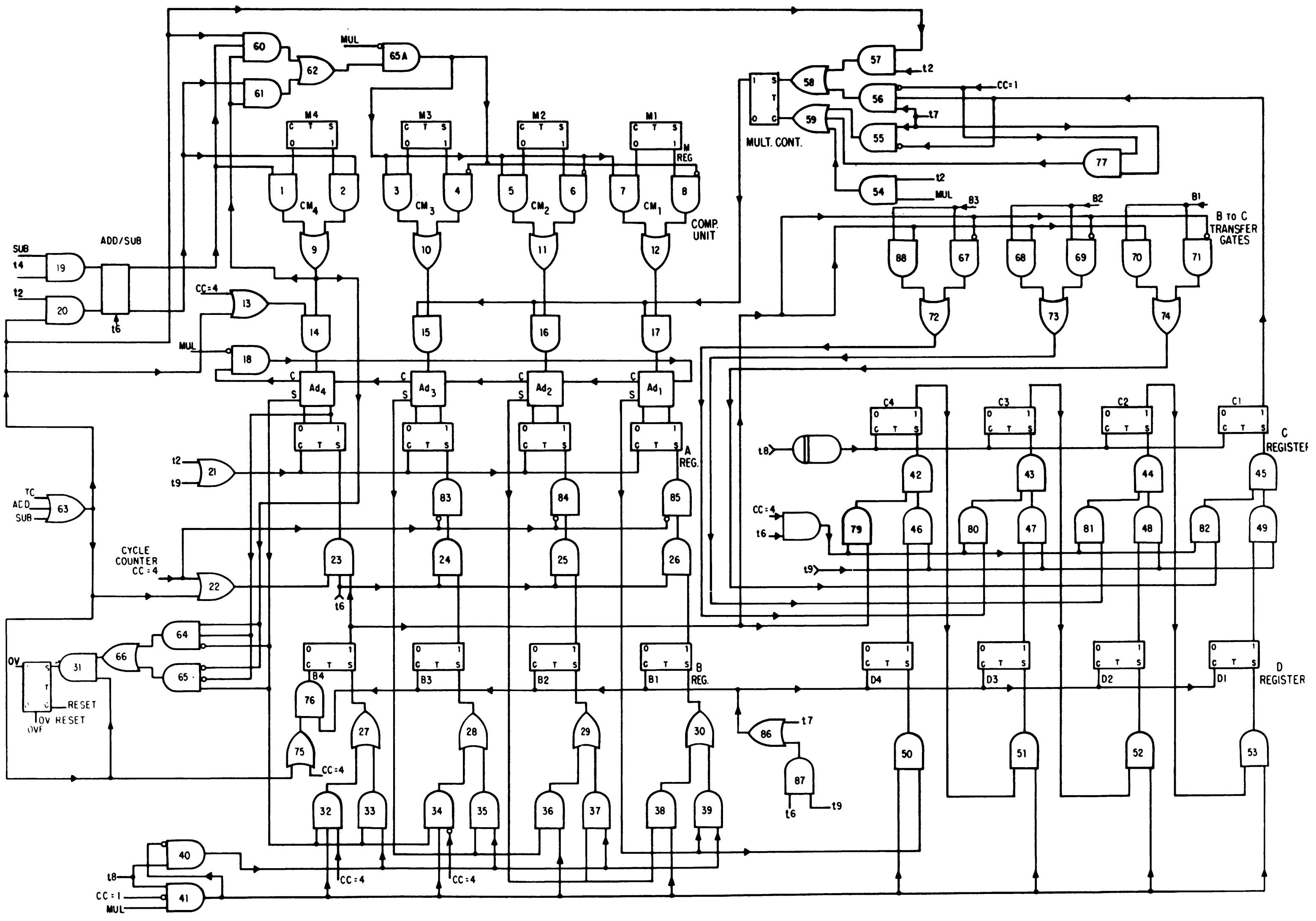

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Figure 11-27.—Logical diagram of a parallel arithmetic unit.

level at gate 13, gate 14 would be enabled if the sign bit were a one.

4. Pulse t4 is not used during this instruction.

5. Pulse t5 is not used during this instruction.

6. At t6 time, the sign and magnitude bits are transferred from the B register to the A register. The t6 pulse is applied to gate 23 through 26. The transfer-clear level is applied to gate 23 through OR gate 22. If any flip-flop in the B register contains a one, t6 will transfer it to the associated flip-flop in the A register, CC =4, a decoded output from the cycle counter, is present when the cycle counter is at four. During the transfer-clear operation, the cycle counter is at zero, making the output of its associated inverter true. Although there is no information present in the B register, the add process is still performed. The contents of the M register are added to all zeros.

7. At t7, the B register is cleared by OR gate 86.

8. At t8 time the sum outputs of the adders are transferred into the B register by way of transfer gates 33, 35, 37, and 39. The sum outputs of Ad_4, Ad_3, Ad_2, and Ad_1 are applied to these gates, respectively. The presence of t8 at gate 40 enables these gates to transfer the adder bits to the B register.

9. At t9 time, the A register is cleared and the transfer-clear operation is complete.

Add

The operation of the sample unit during the add instruction is essentially the same as during the transfer-clear operation. The steps in both sequences are alike except that the add level is generated at t1 and the control gates that were actuated by the transfer-clear level are actuated by the add level. To add, extract the number from its storage location and place it in the M register. Add this number to the number placed in the B register during the transfer-clear operation. Store the sum in the B register. If the sum is positive, store it in its true form; if it is negative, store it with its magnitude bits complemented.

EXAMPLES:

1. Assume that -1 is to be added to -2. The number -2 has been placed in the B register during transfer-clear, and the -1 has been extracted from the memory during ADD. The magnitude bits in the B register are complemented so that -2 is represented as 1101. The number -1 is taken from the memory in its true form, 1001, and placed in the M register. The sign bit is sensed and found to be a negative number. The magnitude bits are complemented and passed to the adder. When the B register contents are transferred to the A register, the inputs to the adder are as follows:

M register complemented		1110 = -1	
A register		1101 = -2	
(Add the one on the left, which is the carry)	1	1011	
		1	end-around-carry
Adder output		1100 = -3	(magnitude bits comp)

The sum, as a result of adding two negative numbers, is a negative number. Observe that the sum has its magnitude bits complemented, as stated in the description of the ADD sequence.

2. It is possible to add a negative and a positive number. For example, to add +4 and -3, the adder inputs are as follows:

Complementer output		0100 = +4	
A register output (comp)		1100 = -3	
	1	0000	
		1	end-around-carry
Adder output		0001 = +1	

Note that an end-around-carry is shown in each example. This operation is incorporated in the sample unit. In fig. 11-27 the carry output from Ad_4 is fed back through gate 18 to Ad_1, the least significant digits adder. Gate 18 is actuated for all except the multiply operation by the inverter in its input. The most significant digit will not change signs as a result of the carry, and the sum will be correct as long as the word length capacity is not exceeded. If the word length is exceeded, an overflow indication will occur.

OVERFLOW.–An overflow condition exists if the sum of two numbers is greater than the maximum number that can be held in the register–greater than ±7 in the sample unit. The possibility of an overflow exists only if two positive or two negative numbers are added; addition of one positive and one negative number cannot produce an overflow. The condition can be recognized readily because when an overflow exists the sign of the sum is different from the sign of the two numbers that were added.

EXAMPLES:

a. +3 = 0011
+2 = 0010
0101 sign does not change

b. -3 = 1100 (complemented)
-2 = 1101 (complemented)
1 1001
1 end-around-carry
1010 (complemented) sign does not change

c. +5 = 0101
+3 = 0011
1000 sign changes; ∴ overflow

d. -5 = 1010 (complemented)
-3 = 1100 (complemented)
1 0110
1 end-around-carry
0111 (complemented) sign changes ∴ overflow

From the examples shown, it is apparent that the equation for an overflow condition is $X_8 Y_8 \overline{S}_8 + \overline{X}_8 \overline{Y}_8 S_8 = \text{OVF}$. X_8 and Y_8 are the sign bits of the augend and addend; and S_8, the sign bit of the sum.

An overflow flip-flop is shown in fig. 11-27. If one of the conditions described by the equation exists, the flip-flop is set to the one state, sounding an alarm, stopping the program, or notifying the operator by some other means that the word limit has been exceeded. The overflow detector network consists of AND gates 64 and 65 plus OR gate 66. Gate 64 is activated by $\overline{X}_8 \overline{Y}_8 S_8$ and gate 65 by $X_8 Y_8 \overline{S}_8$.

Subtraction

To subtract, extract a number from the memory and place it in the M register. Subtract this number from the number located in the B register. Use the same sign notation in the subtract operation as in the transfer-clear and add operations. The logical operation of the complementer during the subtract instruction is different from the logical operation during the add instruction.

Subtraction is performed by the complement and add method. The following examples illustrate complementing requirements.

EXAMPLE 1: Subtract +5 from 0:

0 = 0000
-(+)5 = 0101 complement sign and magnitude of subtrahend and add.
-5

0000
1010
1010

In the above example both the sign and magnitude of the subtrahend were complemented so that the rsult in signed mangitude notation is -5 (1010). This number is then stored in the B register consistent with the form of the sample unit.

EXAMPLE 2: Subtract -5 from 0:

0 = 0000
-(-)5 = 1101 complement sign of subtrahend
+5

0000
0101
0101 = +5

In this example only the sign bit was complemented to indicate +5. The basic conditions and rules of subtraction for the sample unit are:

1. The minuend is in the B register as a result of a previous operation.

2. The subtrahend is extracted from the memory and applied to the adder by way of the M register and the complementer.
3. If the subtrahend is a positive number, both sign and magnitude are complemented.
4. If the subtrahend is a negative number, only the sign bit is complemented.

The subtract sequence with respect to timing pulses and the logic in fig. 11-23 are as follows:

1. At t1 time, the subtract level is generated and applied to the proper gates.
2. At t2 time, the add-sub flip-flop is set to the zero state. The M register is cleared.
3. At t3 time, the subtrahend is entered into the M register from the memory.
4. At t4 time, the add-sub flip-flop is set to the one state. The one-side output of the flip-flop is applied to the zero input gate of the sign complementer CM_4, thereby complementing the sign bit of the number in the M register.

Assume that the number in the M register is -3 (1011). According to rule four, only the sign bit is complemented. There is no output from the complementer (CM_4) at this time, indicating a zero. Since there is no output from the sign complementer, there is no output from the magnitude complement control gate 62; and the magnitude bits remain in their true form.

If the number in the M register is positive, CM_4 will complement the sign, giving an output from gate 9 which, in turn, will complement the magnitude bits via gates 62 and 65.

5. At t5, no operation occurs.
6. At t6, the sign and magnitude bits are transferred from the B register to the A register.
7. At t7 time, the B register is cleared and overflow is sensed.
8. At t8 time, the contents of the adder are transferred to the B register through gates 33, 35, 37, and 39.
9. At t9 the A register is cleared by OR gate 21.

Overflow occurs during subtraction when the absolute magnitude sum of a positive and a negative number exceeds the word length of the sample unit. The overflow conditions that apply to addition also apply to subtraction.

The conditions are again $X_8Y_8\overline{A}_8+\overline{X}_8\overline{Y}_8A_8=$ overflow (OVF), where X_8 and Y_8 are the sign bits of the subtrahend and minuend, respectively, and A_8 is the sign bit of the adders output.

Multiplication

Although multiplication of binary numbers is quite simple with pencil and paper, it is very difficult to mechanize in a computer. Most digital computers multiply by means of the accumulator method. In this method the multiplicand is added if the multiplier digit is a one; but if the multiplier digit is a zero, no addition is performed. The accumulated sum is shifted right one time for each order of the multiplier. The product is formed as a result of repeated additions.

An accumulator unit consists of an adder unit and a register. In the sample unit, the B and C registers are the accumulator registers for the multiplication operation. Assume that 0110 is to be multiplied by 0101. The multiplicand 0110 is contained in the M register, and the multiplier 0101 is contained in the C register. The multiplier bits are shifted out of the C register, and the product that is the result of accumulated additions is held in the B and C registers. The contents of the B and C registers as the multiplication process progresses are shown in table 11-1. The M register is not shown.

Initially the B register is reset to zero, and the multiplier is contained in the C register. The least significant bit of the multiplier is sensed to determine whether addition should occur. After each sense and add sequence, the contents of the B and C registers are shifted right one place. The LSB in the C register is lost at each shift. This is of no consequence since this bit has been used. After the last bit of the multiplier has been sensed and the shift operation has been performed, the product is contained in the B and C registers.

The data flow can be followed in fig. 11-27. The bits in the most significant positions of the two numbers are the sign bits. To determine whether the product is a positive or negative number, the sign bits alone are added. If a negative and a positive number are multiplied, the sum of the sign bits will be one, indicating a negative number. If two negative or two positive numbers are added, the sum placed in the B register will be zero, which indicates a positive product. The result is stored in the most significant position of the B register. After

Table 11-1.—Sequence of operations during multiplication.

	Register		
	B	C	
Initial	0000	0101	
Add 0110	0110	0101	
Shift right	0011	0010	
Add 0000	0011	0010	
Shift right	0001	1001	
Add 0110	0111	1001	
Shift right	0011	1100	
Add 0000	0011	1100	
Shift right	0001	1110	= correct product

this initial addition, the most significant position of the B register is no longer used. Only the magnitude bits that are accumulated in the B register are added.

In general the following steps are involved in the multiplication process:

1. Transfer the multiplicand out of the memory into the M register.
2. Transfer both the sign and magnitude bits of the B register to the C register. Transfer the sign bit of the B register to the A register.
3. Add the sign bit of the M register to the sign bit of the B register. Store the sum in the most significant bit position of the B register.
4. Sense the least significant bit of the C register; if it is a one, add the magnitude bits of the M register to the magnitude bits of the B register. The contents shifted right one place are transferred from the adders to the B register. The least significant bit of the adder Ad_1 is placed in D_1. The contents of the C register are shifted right one place to the D register and then transferred back into the C register.
5. The LSB of the C register is again sensed and the cycle is repeated. The mechanics for addition are carried out each time even if the multiplier is a zero. In that case, the contents of the M register are prevented from being applied to the adder; hence the magnitude bits of the B register are added to zero. The add and shift sequence is repeated until all multiplier bits have been sensed. This is controlled by the cycle counter.

The multiply sequence with reference to the timing pulses is as follows:

Sequence 1

1. At t1 time, the multiply level is generated.
2. At t2 time, the multiple control flip-flop is set to the zero state by gate 54. The cycle counter is set to four (logic not shown). The cycle counter is a down-counter used to keep track of the number of add sequences the computer must perform. Since the multiplier in this problem has four digits, four add sequences must be performed.
3. At t3 time, the multiplicand is transferred from the memory to the M register. This logic is not shown.
4. At t4 time no operations occur.
5. At t5 time no operations occur.
6. At t6 time the sign bit is transferred from the B register to the A register by gate 23. Both sign and magnitude bits are transferred to the C register by the B to C transfer gates. This count of four is decoded from the cycle counter and is applied to gate 22 in the B to A transfer network. The inverted cycle counter signal is applied to gates 83, 84, and 85, inhibiting the transfer of the B register magnitude bits to the A transfer when t6 occurs. The t6 pulse resets the add-sub flip-flop to the zero state. The presence of CC = 4 at gate 13 activates gate 14, allowing the MSB of the M register to be applied to the adder. If both sign bits are ones, the "end around carry" to the LSB of the adder is prevented by the presence of the multiply level at gate 18. The magnitude bits of the M register are not applied to the adder because the multiply control flip-flop is in the zero state.
7. At t7 time, the B and D registers are cleared by gate 86. The least significant bit in the C register is sensed. This is the first multiplier digit. If the LSB is a one, the magnitude bits of the M register are applied to the adder. The one side output of C1 is applied to gate 56 along with t7, switching it on. Its output, in turn, switches the multiply control flip-flop to

the one state via gate 58. Gates 15, 16, and 17 are activated, allowing the magnitude bits of the M register to be transferred to the adder. If the LSB of the C register is a zero, the multiply flip-flop will continue to inhibit the inputs to the adder from the M register.

8. At t8 time, the sign bit from the adder is transferred into B4 by activating gate 41. The sum magnitude bits are transferred into the B register shifted one place to the right.

The multiply level at gate 41 allows transfer pulse t8 to pass. The output of Ad_4 is applied to gates 32, 33, and 34. The count of four in the cycle counter enables gate 32 if the sign bit is a one. Gate 33 is inhibited by gate 40, and gate 34 is inhibited by the inverted CC = 4 pulse. Thus, the sign bit is transferred into B4.

The output of Ad_3 is applied to B2 through gate 36; Ad_2 is applied to B1 through gate 38, and Ad_4 is applied to D4 through gate 50. The magnitude bits are therefore transferred from the adder, shifted right one place and the LSB is the MSB of the D register.

The enabled output of gate 41 also activates gates 51, 52, and 53. These gates allow the C4, C3, and C2 flip-flops to shift their bits one place to the right into the D register.

9. At t8 time, a delayed t8 pulse clears the C register.

10. At t9 time, the contents of the D register are transferred, unshifted, into the C register. This is done by activating gates 46, 47, 48, and 49. The A register is cleared by gate 21. The cycle counter is stepped from a count of four to a count of three, completing one add-and-shift sequence.

Sequence 2

Only a part of the sequence has to be repeated to sense the next multiplier digit. The ring counter starts counting at t6 utilizing the "minor cycle." Although not shown, the minor cycle level is controlled by the cycle counter, which will initiate a minor cycle as long as it does not contain a count of four or zero. The minor cycle operation is as follows:

1. At t6 time, the magnitude bits of the B register are transferred to the A register. The absence of CC = 4 uninhibits gates 83, 84, and 85, and prevents the transfer of the B register bits to the C register as was done in sequence one to obtain the initial multiplier. Gate 78 is blocked, inhibiting gates 79, 80, 81, and 82.

2. At t7 time, C1 is sensed. If it is a zero, the multiply flip-flop is reset to zero. The magnitude bits in the M register are removed from the adder inputs since gates 15, 16, and 17 are no longer enabled. Gate 14 prevents the sign bit M4 from entering the adder. If C1 is a one, the conditions are the same as they were in sequence 1.

3. At t8 time, the transfer-shift operation is performed. Since the cycle counter does not have a count of four, the sign bit in Ad_4 is shifted right one place into B3 by the activated gate 34. The adder's magnitude bits are shifted right into the B and D registers as previously described. The contents of the C register are transferred and shifted right into D.

4. At $t8_D$ time, the delayed t8 pulse clears the C register.

5. At t9 time, the contents of the D register are transferred to the C register. The cycle counter is stepped to two, completing sequence two.

Sequence 3

The minor cycle is again repeated for the third multiplier digit. The contents of C1 is sensed. If it is a one, the magnitude bits of the M register are added to the contents of the B register and a shift is performed. If C1 is a zero, the contents of the B register are added to zero and a shift is performed. The various transfer functions are then performed and the cycle counter is set to one, completing sequence three.

Sequence 4

The three magnitude bits of the multiplier were sensed and shifted in the first three sequences. In sequence four, the bit contained in C1 is the sign bit of the multiplier. It was originally placed in C4. The sign bit of the multiplier should not be considered as a multiplying digit. The CC = 1 input blocks gate 56 and activates gate 55 at t7 time, setting the multiply control flip-flop to the zero state and inhibiting gates 15, 16, and 17. Therefore, the contents of the M register cannot be added to the bits in the B register during CC = 1. The last transfer-shift cycle is then performed, producing the correct product in the B and C registers.

MULTIPLICATION OF NEGATIVE NUMBERS.–The logical diagram does not show all the gates that are needed to multiply by a negative number. If the multiplier originally contained in the B register were a negative number, the magnitude bits would be complemented. They would have to be changed to their true form before being sent to the C register.

ROUNDOFF.—The word length of the product frequently exceeds the capability of the machine. When it does, a round-off procedure is generally used, and only the bits in the B register are retained since they are the most significant digits. If the bits in the C register are 1000 or more, a one is added to the least significant bit in the B register. It must be remembered that a practical computer has a word length much longer than four bits. Therefore, the bits lost during roundoff in a practical computer have much less significance than those in this sample machine.

Division

As mentioned in the introduction, division is not performed in this sample machine. The number of additional elements required make showing the divide operation impractical. An examination of the division process will show the requirements of the arithmetic unit.

Binary division can be done by using the longhand method in the same manner as decimal division, as shown in the example below:

Decimal

$$\begin{array}{r|l} & 3 \\ \hline 4 & 12 \\ & \underline{12} \\ & 0 \end{array}$$

Binary

$$\begin{array}{r|l} & 11 \\ \hline 100 & 1100 \\ & \underline{100} \\ & 100 \\ & \underline{100} \\ & 0 \end{array}$$

In both the decimal and binary systems, division can also be performed by successive subtractions. The total number of subtractions required is the quotient.

Decimal

$$\begin{array}{rl} 12 & \\ -\ 4 & \\ \hline 8 & \text{1st subtraction} \\ -\ 4 & \\ \hline 4 & \text{2nd subtraction} \\ -\ 4 & \\ \hline 0 & \text{3rd subtraction} \end{array}$$

Binary

$$\begin{array}{rl} 1100 & \\ -\ 100 & \\ \hline 1000 & \text{1st subtraction} \\ -\ 100 & \\ \hline 100 & \text{2nd subtraction} \\ -\ 100 & \\ \hline 0 & \text{3rd subtraction} \end{array}$$

The mechanized process combines characteristics of both these methods. In binary division:

1. Each time a subtraction leaves a positive remainder, a one is placed in the quotient.
2. Each time a subtraction leaves a negative remainder, a zero is placed in the quotient.
3. The remainder is shifted left one place with respect to the divisor after each subtraction.

Using these rules, the solution of the sample problem is as follows:

Dividend	1100
Divisor	100
Remainder	0100
1st quotient bit	1
Shift remainder left	1000
Divisor	100
Remainder	0
2nd quotient bit	1

Therefore, the total quotient would be 11. A comparison of this method and longhand division shows that the relative positions of the divisor and the dividend are the same. In the longhand method, 100 is first divided into 110 (the three most significant bits in the dividend). In the successive subtraction method, 100 is subtracted first from the three most significant digits since they are divisible by 100. Since the divisor is smaller in value than the first three digits, the first quotient bit is a one.

In the longhand method, the remainder as a result of the first subtraction is 10, and the next dividend digit is brought down so that the new remainder is 100. The divisor is divided into this remainder, and the result is one. In the successive subtraction method, the same relative positions of the divisor and remainder must be maintained in the computer. Hence, the remainder is shifted left one place before the next subtraction is performed. Since the divisor is not larger than the remainder, the second quotient bit is one.

In the previous example no zero was generated in the quotient. The following case will illustrate what steps are taken to generate a zero. Divide 45 by 9 using the longhand method.

```
             101
          ________
    1001 |1001101
          1001
          ________
            1001
            1001
           ______
```

Bringing down the next digit will result in a remainder that is smaller than the divisor, calling for a zero to be placed in the quotient.

The successive subtraction method on the same problem results in the following:

Dividend	101101
Subdivisor	1001
Remainder	001001
1st quotient bit	1
Shift remainder left	010010
Subdivisor	1001
	101110
2nd quotient bit	0
Restore-add	101110
	1001
	010010
Shift remainder left	100100
Subdivisor	1001
	0
3rd quotient bit	1

Again the total quotient is 101.

The result of the first subtraction is a positive number. The remainder is shifted left one place, but is still smaller than the divisor. After the subtraction is performed, a negative remainder results. The computer detects this by noting that the MSD will require a borrow. This excess borrow is called an "overdraw."

When an improper subtraction is performed, the remainder must be restored to its original value before the next operation. This is done by adding the divisor to the remainder before the next shift occurs. This is called a restore-add operation.

Division Mechanization Problems

Three mechanization problems arise in division operations: determining the correct position of the divisor with respect to the dividend, detecting an overdraw, and storing the quotient.

The initial problem is to determine the correct position of the divisor with respect to the dividend. If a binary 25 were divided by a binary 5, the relative positions would be:

```
11001
101
_____
```

However, if the divisor were a binary 7, the positions would have to be:

```
11001
0111
_____
```

One method of solving this problem is to aline the most significant bits of the dividend and the divisor; then subtract. If an overdraw occurs in this initial subtraction, the relative positions are incorrect, and an additional order of the divisor must be used.

To obtain the proper order, a restore-add operation is performed, shifting the divisor one place to the right. Subtraction is then repeated. If no overdraw occurs, the order is correct.

Detecting an overdraw is the second problem. Subtraction is usually done by complementing and adding. Whenever the subtrahend is smaller than the minuend, an end-around-carry develops when the subtrahend is complemented and added to the minuend. No carry develops if the minuend is smaller. When there is no end-around-carry, an overdraw has occurred.

In figure 11-28, a carry allows an overdraw control flip-flop to be set to the one-state when a sample pulse occurs. The absence of a carry allows the flip-flop to be reset to the zero state. The state of the flip-flop determines

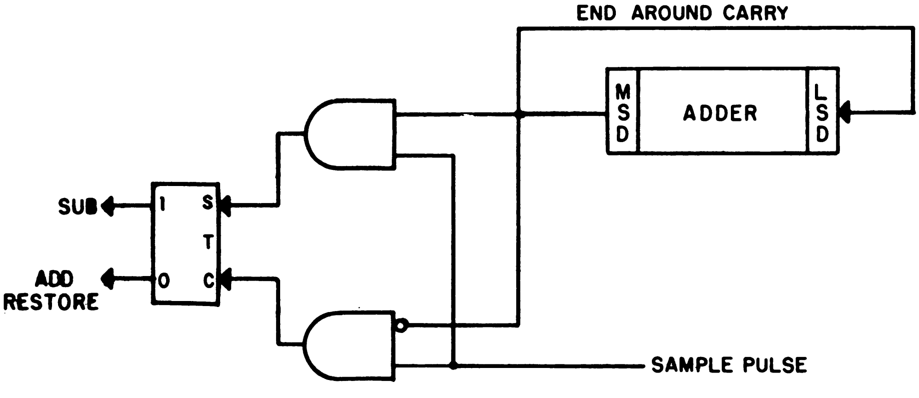

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Figure 11-28. –Overdraw detect network.

whether the following sequence is to be a subtract sequence or a restore-add sequence.

A third problem is the storage of quotients. The quotient bits can be stored in a shift register. A quotient sampling pulse will allow a one to be placed in the least significant position of the shift register if the overdraw flip-flop is in the one state as a result of a successful subtraction. A subsequent shift pulse will place the bit in the next position of the register and the cycle is ready to start again.

In the problem above, the final remainder was always zero. In a practical problem this is rarely the case. The division process is repeated as many times as necessary on the remainders to the right of the binary point to produce the desired accuracy, limited, of course, by the bit handling capacity of the particular unit being used.

Ballistics Computer
Square Root Operation

The square root of a radicand is determined one bit at a time by a process of comparisons and subtractions. Each comparison produces a remainder upon which the subsequent comparison is based. Subtractions are performed by the one's complement method with the addition of a one to this result in the least significant bit position to produce subtraction by the addition of the two's complement. The root is built up in the quantity being subtracted from successive remainders. Since the subtraction is done by the complement method, the answer is also complemented and requires conversion to be placed in its proper form.

In computing the first digit, the first step is doubling the radicand and subtracting from it one-half to obtain a remainder. This is the same as determining if the square root of the radicand is equal to or greater than one-half. When the remainder is positive, the first digit is a one, this remainder is stored and a one-half is also stored in the quantity being subtracted from successive remainders. When the remainder is negative, the first digit of the root is a zero, the result of the subtraction is not stored, and one-half is not stored in the quantity being subtracted from successive remainders. In this case, the remainder obtained is simply twice the radicand. To compute the second digit, a similar comparison is made with respect to twice the remainder. As the third and each succeeding digit is computed, the previous remainder is doubled, a subtraction is made, and the sign of the result of the subtraction is determined. The subtraction is stored if the result is positive and is not stored if the result is negative. When the result of the subtraction is negative, twice the preceding remainder is stored. The stored result is the new remainder. At the end of the word-time during which the root is extracted, the root is present in its one's complement form with a one in the least significant bit position. When this quantity is inverted, the result is the root in true binary.

To compute, for example, the square root of radicand 0.01000:

1. Double the radicand by shifting it left one bit position:

0.10000

2. Subtract one-half from result obtained in step one by adding the one's complement of one-half with an LSB one digit carry to form the two's complement:

0.10000 = 1/2

1.01111 = -1/2
1

0.00000

3. Since the sign bit from step two is zero, store 0.00000 as R1.

To compute the second digit of the root of 0.010000:

1. Subtract 5/8 from R_1 by adding the one's complement of 5/8 with an LSB one digit carry to form the two's complement:

0.00000

1.01011 = -5/8
1

1.01100

2. Since the sign bit of step one is one, store 0.00000 as R_2.

To compute the third digit of the root of 0.010000:

1. Double the previous remainder (R_2) by shifting it left one bit:

0.0000

2. Subtract 9/16 from result obtained in step one by adding the one's complement of 9/16 with an LSB one digit carry to form the two's complement:

0.0000

1.0110 = -9/16
1

1.0111

The root is stored in the quantity being subtracted from previous remainders and is in its one's complement form. Also, the last digit of the number being subtracted is always set to one. This results in an answer correct to one less significant digit than there are number digits used or, in the computer, 18 minus 1 (or 17). In this example, the number being subtracted becomes 1.0111. The root is obtained by complementing 1.0111, which is 0.1000. Thus, the square root of 0.01000 is 0.1000 (the square root of 1/4 is 1/2).

INPUT UNIT

The input section translates input information into the digital form suitable for processing by the arithmetic unit. It also delivers necessary signals to the control and output groups to accomplish display functions.

Inputs in the form of shaft positions and voltages are periodically sampled in accordance with the internally stored program. The analog inputs are obtained from 13-bit shaft encoders and from data-link pulse trains.

The input unit assures the arrival of input data from the sensors at the predetermined destination at the precise time necessary to permit the solution of a particular set of equations. Basic computer inputs come from the shaft position encoders, the keyboard, analog-to-digital converters, the six-word buffer, and ballistic constants.

Keyboard Inputs

The keyboard enables the B/N to enter numerical data into the computer. The keyboard control panel was discussed earlier in the chapter under input controls.

Analog-to-Digital Converter

The analog-to-digital converter converts six analog voltages to equivalent nine-bit binary numbers, plus a sign bit. The inputs are d-c analog voltages ranging from -5 to 0 volts. A 0-volt input produces a maximum positive binary number: a -2.5-volt input produces a binary zero; and a -5-volt input produces the maximum negative binary number.

Six Word Buffers

The six words of the buffer occur sequentially, each word appearing 25 times per drum revolution. The words are, in order of appearance: starboard doppler, port doppler, time word, intervalometer, extrapolator, and tape control.

Shaft Position Encoders

Shaft position encoders are electromechanical devices used to generate a binary number representing the angular position of an attached shaft. This encoder shaft is usually connected to the shaft of a motor or potentiometer via a gear train. The basic element of the shaft encoder is an encoder disk; these were briefly discussed earlier in the chapter. The encoder disk contains concentric bands having segments of conducting and nonconducting material, arranged in a binary-coded pattern. (See fig. 11-6.)

ENCODER SELECTION.–There are a total of 25 inputs to the computer that are classified as encoder inputs. Five of these 25 inputs are servo-driven encoders. The servos are driven by various types of analog voltages originating in different subsystems of the A6-A aircraft. Six of the 25 inputs are binary switches, 7 bits per set. Each switch, however, is scanned by the computer as if it were an encoder. The remaining 14 encoder inputs, (13 added for effectivity A⃤), are encoders located throughtout the aircraft. All of the inputs are applied to an input encoder junction box, internal to the computer. The junction box provides the necessary isolation among all the inputs to the junction box. The wires from the junction box are connected to the computer and scanned every word time. The voltages on these output lines from the junction box depend on the position of the encoder selected by the computer.

OUTPUT UNIT

The output unit converts selected information from digital to analog form and generates servo signals, analog voltages, and discrete signals. Output signals also control illumination of indicator and alphanumeric displays which reflect ballistics computer operating conditions and solutions. These outputs are controlled by computed results obtained primarily from the SA and MADSU.

Servo, analog, and discrete output information is stored on an output buffer. Information recorded on an output addressing track controls the conversion of output buffer data into suitable output form. This track selects the conversion circuit corresponding to the destination of output buffer data. Servo output circuits generate and control the generation of servo signals, while digital to analog circuits convert digital information into analog voltage form. Discrete signals are generated as outputs from current-switching circuits to control on-off functions for relatively long periods with respect to computer iteration time. These signals control the appearance of visual markers on display devices, open and close control circuits, control the illumination of indicators, and are used as signals of computer operation.

Alphanumeric displays in the form of tape assemblies (tape displays) are controlled by a tape display addressing track on the memory drum. Tape data can be obtained either from the MADSU or the keyboard.

PROGRAMING

A digital computer can add or subtract almost indefinitely, and with lightning speed. For this speed to produce meaningful results, the computer must be supplied with complete instructions, including what, when, where, and why, before each operation. The speed, accuracy, and versatility of the computers are determined by the type of instructions provided and the manner in which they are given.

The last portion of this chapter is roughly titled Programing; roughly, because programing is technically only one part of preparing a problems for solution by a computer. Actually there are four major steps as shown in fig. 11-29 numerical analysis, programing, coding, and checking. These jobs are frequently referred to collectively as programing.

NUMERICAL ANALYSIS

Essentially, numerical analysis is the first step—the definition, in proper mathematical terms, of the problem to be solved. It is the science, or frequently the art, of reducing real problems into terms, quantities, and equations that a digital computer can accept. In all but the simplest problems, extensive numerical analysis may be required before the program can be written. How does one represent an integral or differential, a cosine, or a quality? Numerical tricks, approximations, and even arbitrary values must be used in order to translate these concepts into the individual numerical values required by the computer.

PROGRAMING

Normally problems are too long and too complex to encode directly from the mathematical analysis. Programing provides the shorthand, or guide, which makes it possible to translate the mathematical operations,into the step-by-step operations required by the specific computer to be used. Programing is primarily the task of drawing flow charts, or

A NUMERICAL ANALYSIS

Problem: Determination of position

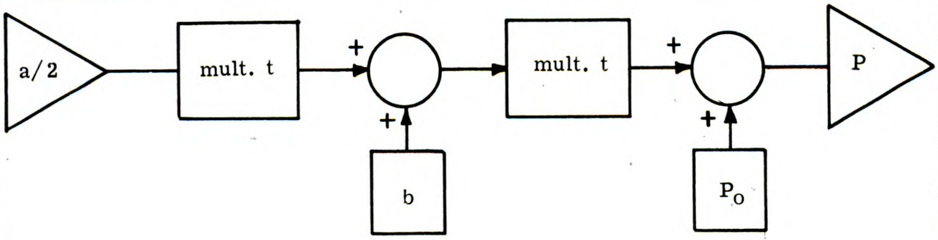
$$P = \frac{a}{2} t^2 + bt + P_o.$$

a = acceleration

b = velocity

P_o = position at t = 0

B PROGRAMING



C CODING

INST. NO.	INSTRUCTION
1	Read in a/2
2	Multiply by t
3	Add b
4	Multiply by t
5	Add P_o
6	Read out

D CHECKING

INST. NO.	
1	$\frac{a}{2}$
2	$\frac{a}{2} t$
3	$\frac{a}{2} t + b$
4	$\frac{a}{2} t^2 + bt$
5	$\frac{a}{2} t^2 + bt + P_o$

$$P = \frac{a}{2} t^2 + bt = P_o$$

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Figure 11-29. –Four steps of programing.

block diagrams, and planning memory allocations.

A flow chart (fig. 11-30), essentially an annotated block diagram, is an organizational convenience. In addition to depicting the overall system logic, it shows the sequence of logic operations, the result of each choice, and the time and entrance point of all new data.

Although it is intended principally as an aid in writing the computer code, the flow chart is also an excellent troubleshooting and testing device. It has symbols to describe the various functions to be performed, to indicate a logical choice or optional sequence, and to show when a sequence is changed by new or modifying instructions. Additional symbols and conventions are generally used to simplify the diagram and to make it a more complete instrument for aiding the man writing the code. These symbols are not standard, but they are consistent in a given set of charts. Their sole purpose is to transfer information from the designer to the coder or other users of the computer.

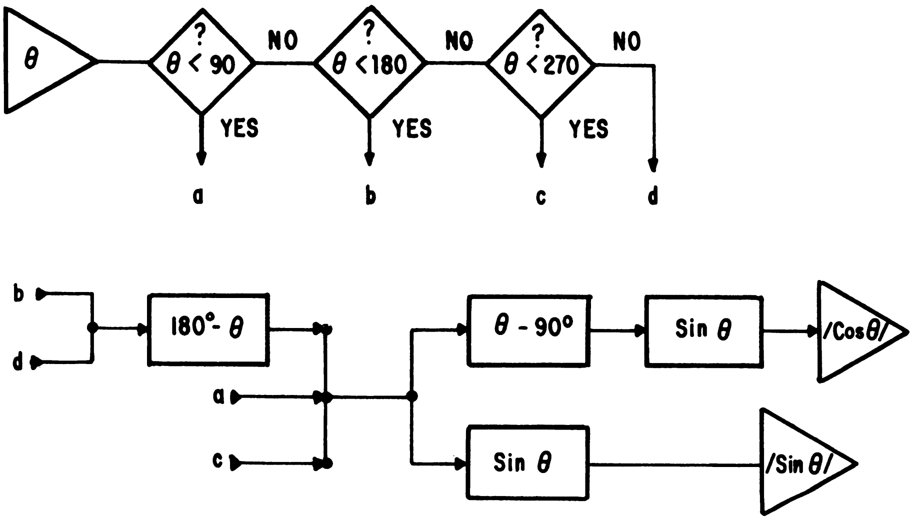

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Figure 11-30. –Flow chart: determination of sine and cosine.

CODING

Coding is the step-by-step transformation of the problem, as mapped out by the flow chart, into a final program written in the language of a particular computer. Coding is essentially a painstakingly precise bookkeeping operation: each address, each digit, and every single command must be correct.

The coder, unlike the man who writes the flow chart, needs little knowledge of mathematics; he does not even need to understand computers. The only absolute requirement is that he adhere inflexibly to the rules as established by the design of the computer. Generally, in transferring from one type or model of computer to another, the coder must learn a new set of rules, a new language, or a new code.

CHECKING

Checking, or verifying, is the final step in what might be called the training of a computer. It is frequently performed automatically. The sole purpose of this step is to insure that the coder has made no errors. The program prepared by the coder may be stored internally or externally. Storage will be semipermanent or permanent depending upon the purpose and application of the computer.

SAMPLE PROBLEM

The following example represents a simple subroutine in a single address computer. This example was selected because it is farily short and quite representative of one method of coding.

The problem is to determine the sine and cosine of an angle which is supplied to the computer in binary form. The first step of the subroutine will arbitrarily be called step one, although the subroutine could appear anywhere in the complete program. If it had to be moved, moving it would be a simple matter of renumbering each step, being certain to maintain the proper sequence.

The operations and operation codes, not addresses, used in this computer are listed in table 11-2. (For this computer, an address is defined only in connection with an operation; for instance, address 8 with operation 06 means "transfer the contents of the accumulator (AC) to memory register (mr) four"; and address 8 with operation 07 means "read input data at address 8 into the input register (IR)." Address 8 is not used with any other operation.)

This particular system is very useful in developing a high speed special purpose computer; however, changing an address-operation combination requires a physical modification of the computer.

Now, with the addresses and instructions given and the flow chart as shown, the actual program is ready to be written. The first step, read in angle theta, will be arbitrarily numbered instruction one. Remember, as stated above, it could appear anywhere in the program.

For the next instruction, compare theta against 90°, it may be necessary to supply the 90° as another input or it may be moved into the register from storage in memory. In a special purpose computer the digital representation for 90° can be easily stored: the method of representation depends on the computer. Assuming that the angle theta is represented by a seven-bit binary number in which the most significant digit represents 180° and the least significant bit represents 2.8°, if a 1 is supplied to only the second most significant digit position (0100000), the effective angle input will be 90°.

Since both of the angles involved are positive, the compare operations simply supplies the difference to the accumulator. If theta is greater than 90°, the sign will be positive; it it is less than 90°, it will be negative.

Rather than go through an extensive writing process, the coder, or programer, uses a tabular bookkeeping form which varies the type of computer and the code being used.

Table 11-2.—Code table.

Operation code	Operation
01	Add (AC) + (mr) → AC
02	Subtract (AC) - (mr) → AC
03	Multiply (mr) · M/DR → AC
04	Divide (mr) + M/DR → AC

05	Compare
	if (AC) ≥ (mr), sign AC = +
	if (AC) ≤ (mr), sign AC = -
	if sign of (AC) = + and sign of (mr) = +, AC - mr → AC

06	Serial transfer AC → mr or mr → AC
07	Read in in → IR
08	Read out AC → OR
09	Conditional jump if sign AC = -, J → PR
10	Conditional jump if AC = 0, J → PR
11	Unconditional jump J → PR
12	Enter subroutine PR → TPR, J → PR
13	Exit subroutine TPR + 1 → PR
14	Read into memory register K(i) → mr
15	Recycle/stop J → PR

Since this example is to be coded for a special purpose computer, it is permissible to take a few short cuts: addresses will be wired in; input and output connections will be permanent; and all data concerning type of quantity and units of measure will be "remembered" by location. Thus for a particular operation and address combination, the digital shaft encoder (or other angular indicating device) automatically supplies the angle theta to the accumulator at the proper time.

In the single address code, as shown in table 11-3 the operation specifies the quantity or quantities and the method of combination. The address tells where the result is to go. For example, instructions three says to subtract the absolute value of the contents of the input register from the contents of the accumulator. It further states that if both values were positive (which they must be in this case), the result will carry a positive sign if, and only, if, the magnitude of the accumulator value is greater than that in the input register.

Table 11-3.—Sample coding sheet.

Instruction	Code		Operation
	Oper	Add	
1	08	08	8 → 1R
2	06	10	1R → AC
3	05	10	/AC/-/IR/ → AC
4	11		AC = -? Jump to step 15

This single address code thus gives:
1. The first quantity.
2. The operation to be performed.
3. The second quantity.
4. The directions for storage or use of the result of the operation.

Its advantages are speed and simplicity —one instruction per operation. Building such devices becomes progressively more difficult as the number of operations, instructions, or addresses is permitted to increase, since each permissible combination of quantities, storage addresses, and functional operations must have a different operation and address code. The instruction itself may contain the code. In other words, the binary representation of the instruction may be wired to connect and operate the proper gates.

The coder need not worry about these items, his code books enable him to write the code directly from the flow chart. Thus he reads in theta, then compares it against 90° (0100000), which may have been stored in one of the memory registers permanently, or temporarily, as part of this subprogram. In step three, compare, it has been assumed that the constant was already available. The compare function is permitted against any of the memory registers. Step four, the conditional jump, is represented by the decision box in the flow chart, while step three is represented by the contents of the box. Therefore, four means: if the result of step three is positive, proceed to the next step; if the result is negative, skip (jump) to step number–. Ordinarily the coder will fill in the number of this step when he completes the program and determines where in the sequence the particular step appears.

When the code has been completed and checked for accuracy and consistency, the program is ready to be wired in. After this has been done, any change of operation or sequence will necessitate modifying the computer.

If the problem discussed were prepared for solution by another type of computer, it might be programed in an entirely different manner. It is entirely conceivable that complete sine and cosine tables might be stored directly in memory, eliminating the need for this subprogram. It is more likely that in another computer, inputs would be supplied in terms of the sine and cosine of angle theta rather than the angle itself, again eliminating the need for this subprogram.

The previous discussion covers a tremendously simplified view of the total programming problem. To design, build, and program a military digital computer requires attacking the design problem on all fronts at once: how many specific equations are to be solved, how many and what kind of inputs will be supplied, what type of outputs will be required, what speed and accuracy will be required, and how much weight and space may be devoted to the computer. These factors are all independent and greatly affect the particular course taken in developing the program.

CHAPTER 12

PRINCIPLES OF INERTIAL NAVIGATION

The introduction of aircraft with inertial navigation systems creates a whole new set of problems in operation, maintenance, and deck handling. This chapter introduces the fundamentals of inertial navigation and discusses the effects of component and initialization errors. Initialization is the process of bringing the inertial system to a set of initial conditions from which it can proceed with the navigation process. A description of system initialization on the ground and on board aircraft carriers is given. Carrier environment is emphasized since it is the most difficult with which to deal.

NAVIGATION

There are two methods of navigation. One is position fixing by measuring position relative to some known object. The most common example is celestial navigation. Loran is another example of navigation by periodic position fixes. The other method, dead reckoning, measures speed and heading and, using these measurements, computes position change from an initial position fix. The most common example of this form of navigation is the ship navigator's position plot. One of the oldest automatic navigation systems is the dead reckoning analyzer, which takes its speed from the ship's log and its heading from the ship's gyrocompass to compute latitude and longitude. A more accurate automatic dead reckoning device is the Doppler radar navigator.

Navigation systems which require a continuous record of position normally use both methods; that is, since it is not always convenient to establish position continuously by a direct fix, they dead reckon between position fixes. However, the error in dead reckoning as a percentage of the distance traveled commonly reaches 2 to 5 percent. Thus, as the distance traveled between fixes increases, as in the case of high speed aircraft, the accuracy of dead reckoning must be increased if a small absolute position error is to be maintained.

DEAD RECKONING

The concept of dead reckoning is well known, but the sources of error and methods of increasing the accuracy of dead reckoning are not. To navigate by dead reckoning, the vehicle's speed is resolved, using the vehicle's heading, into north and east velocities. The time integral of these velocities gives the distance traveled or the change in latitude and longitude from the last position fix.

The two major causes of error in position computed by dead reckoning are errors in the measurements of heading and speed. A heading error of 1° introduces an error of 1.75 percent of distance traveled, and a speed error of 1 percent introduces an error of 1 percent of distance traveled. Assuming these errors to be uncorrelated, the total system error becomes $\sqrt{1.75^2 + 1^2}$, or about 2 percent of distance traveled. Increasing the accuracy of the speed and heading measurements increases the system accuracy; however, the errors cited above approach the limits of precision of present Doppler navigation equipment.

Fundamentals of Integration

Since the process of integration is so frequently used in navigation systems, a simplified explanation is given. (NOTE: Integration is also discussed in chapter 13 of Aviation Fire Control Technician 3 and 2.) In inertial navigation, distance traveled is calculated from measured acceleration by first integrating acceleration with respect to time to find velocity, and then integrating velocity with respect to time to find distance traveled. From elementary calculus, distance, velocity, and acceleration are related as follows:

$$x = \int V\,dt = \int\int a\,dt\,dt$$

This formula indicates that distance (x) is equal to the integral of velocity (V) with respect to time and is also equal to the double integral of acceleration (a) with respect to time. The three graphs (fig. 12-1) illustrate the relationships with acceleration, velocity, and distance.

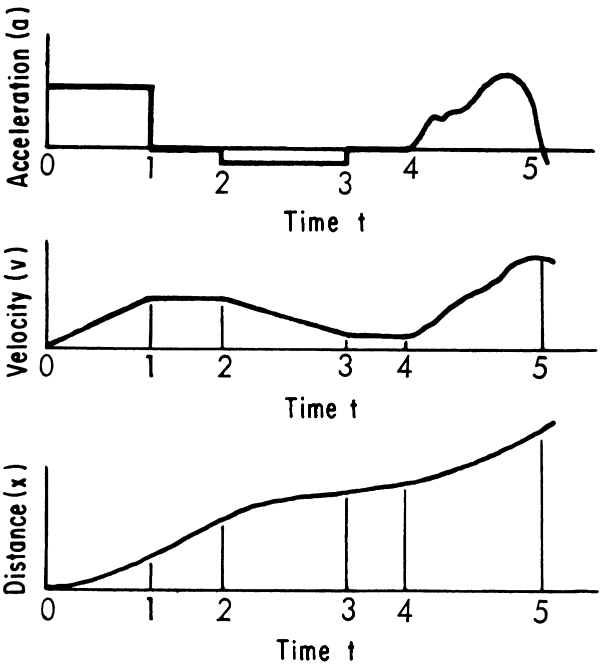

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Figure 12-1. -Integration of acceleration to obtain velocity and distance.

In order to illustrate these relationships clearly, constant values of acceleration are chosen for each of the first four intervals (time 0 to time 4). Integrating the constant acceleration for time 0 to time 1 gives a velocity (V) which increases linearly. Velocity at the end of the first interval is actually computed by measuring the area under the acceleration curve (time 0 to time 1).

Recall that the fundamental formula for velocity is $V = a \cdot t$. The process of integration actually subdivides each interval shown in figure 12-1 into an infinite number of tiny intervals. Integration is, then, the process of adding, or summing, an infinite number of incremental areas under a curve to obtain the total area. The velocity curve, therefore, is a plot of subtotals of the incremental areas under the acceleration curve.

In the second period, the acceleration is zero, and the velocity remains constant. In the third period, there is a constant negative acceleration which reduces the velocity subtotals at a constant rate. In the fourth period, there is no acceleration and no change in velocity. In the fifth period, a random acceleration and its approximate integral, the velocity, are shown.

The distance curve is actually a plot of subtotals of the incremental areas under the velocity curve.

A practical example, the ball and disk integrator, is shown in figure 12-2. It is rarely used in inertial navigators, but a very similar device is commonly used in analog computers. The ball (B) is mounted on a splined shaft which is free to turn in bearings. The input to the integrator is the distance a (acceleration in this example); that is, the distance between the ball and the center of the disk. The disk rotates at a constant angular rate and its angular position (θ) is directly proportional to, or varies directly as, time (t), (that is, as shown in figure 12-2, $\theta \propto t$). Rotation of the splined shaft is the output of the integrator, and its angular position θ is directly proportional to velocity (V) in this example. If a is zero (the ball is at the center of the disk), the constant disk rotation will not cause the output shaft to rotate, indicating that present velocity is constant. If the ball is displaced from the center of the disk a distance a, disk rotation causes the splined shaft to rotate, indicating that velocity is increasing. Moving the ball to the left of center of the disk simulates negative acceleration and causes the splined shaft to rotate in the opposite direction, reducing the indicated velocity.

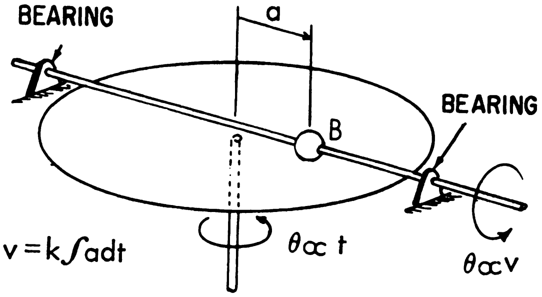

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Figure 12-2. -The ball and disk integrator.

Another example of integration is a simple motor driving a counter. If a voltage proportional to velocity is present, it could be used to drive a motor so that the speed of the motor would be proportional to velocity; and the number of revolutions or the counter reading would indicate distance traveled. Thus, velocity would be integrated to find distance.

INERTIAL NAVIGATION

An inertial navigation system is a dead reckoning system with very good accuracy. Instead of measuring speed directly, the system derives it from measurements of the vehicle's accelerations. Two accelerometers are used; one accelerometer is pointed north, and the other is pointed east. The first integral with respect to time of these accelerations gives the north and east changes in velocity, and the second integral with respect to time gives the north and east position changes. Of course, the vehicle's initial velocity and initial position must be inserted for accurate navigation.

The accelerometer can be made to measure acceleration very accurately; however, it cannot distinguish between accelerations of the vehicle and the effect of gravity. This difficulty can be eliminated by keeping the sensitive axis of the accelerometer perpendicular to the gravity vector at all times. To accomplish this, the accelerometers are mounted on a three-axis, gyrostabilized platform.

The platform (fig. 12-3) is attached to the vehicle through a gimbal system which permits it to take any orientation with respect to the vehicle. Three gyros are mounted on the platform with their input or sensitive axes in three mutually perpendicular directions. The gyros have the property of sensing angular rates about their input axes. A sensed rate causes the gyro to precess around its output axis, providing an electrical output from the gyro which is amplified and used to drive a platform control torquer to null out the sensed rate. Thus, if the vehicle rotates about any of its three axes, the platform tends to rotate; and the rotation rate is sensed by the gyros. The resulting gyro output causes the platform to be driven in the opposite direction, thus keeping the platform space stabilized while the vehicle rotates around it. Mounting the accelerometers on this platform preserves their orientation independent of the vehicle's rotation. The gyros shown in figure 12-3 are the single-degree-of-freedom type.

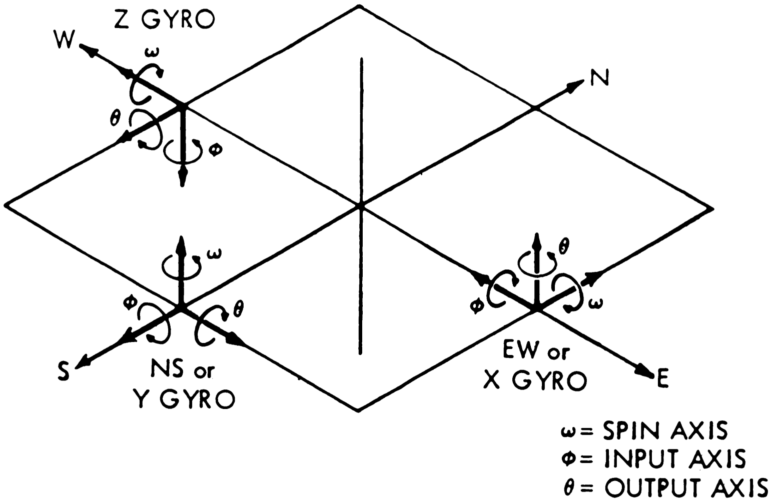
Since the integral of angular rate with respect to time is an angle, the platform is commonly described as an integrator. The angle through which the platform moves relative to the vehicle is equal to the negative integral of the vehicle's angular rate.

All is not yet solved. There is one rotation of the vehicle that should be taken into account in orienting the accelerometers. This rotation arises from motion over the earth. (Refer to fig. 12-4.) The vehicle moves from point A to point B. In doing so, it rotates through an angle θ so that it remains level, or perpendicular to gravity. If the platform does not rotate, it will take position shown at B; and the accelerometers will sense gravity. It is now apparent that the platform must be more than space stabilized; it must be stabilized with relation to the earth, and it will take more than just the output of the gyros controlling the platform torquers to do this.

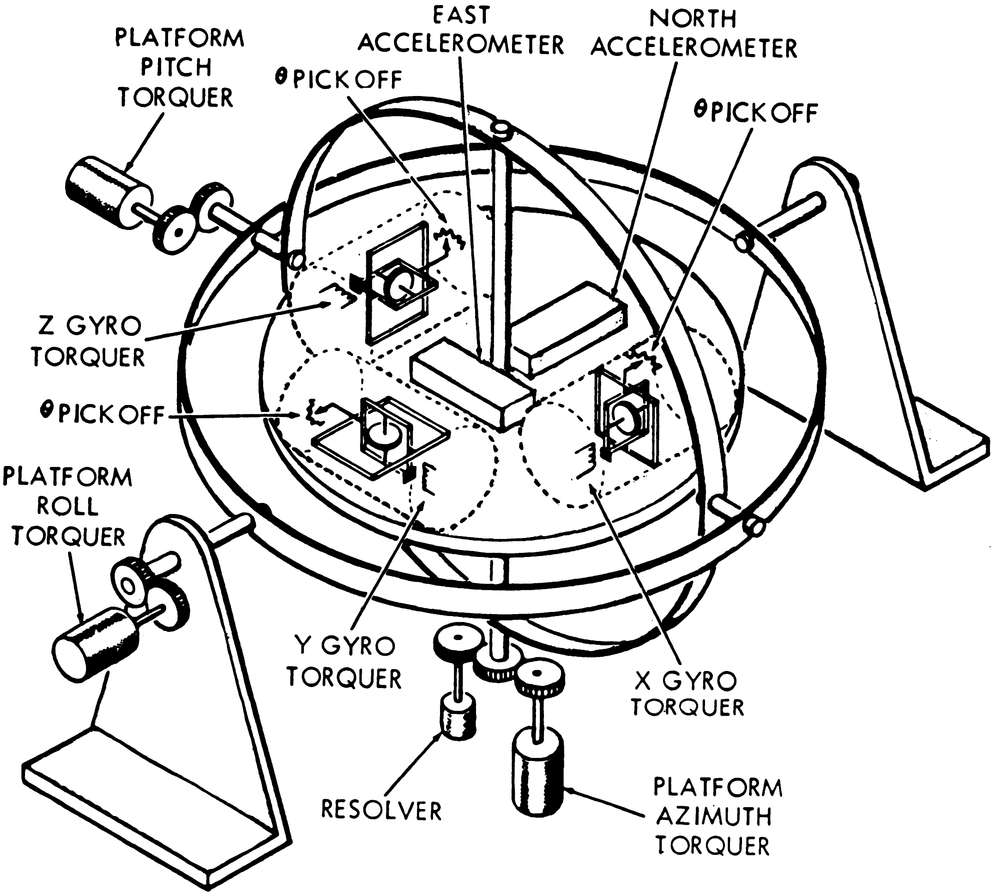
Since the platform integrates the input rates, an artificial input equal to the negative of the vehicle's angular rate would keep it level. The vehicle's true angular rate ω_T, in radians per hour, while the vehicle is traveling over the earth, is V_T/R, where V_T is its true linear velocity, and R is the radius of the earth. This artificial signal would be applied to the gyro torquer, which will cause the gyro to move a few degrees around its output θ axis and produce a signal from its θ pickoff even though the input ϕ axis senses no angular rate. By torquing the gyro with $-V_c/R$, where V_c is the computed value of V_T, the gyro θ pickoff output will cause the platform to rotate through an angle relative to the horizontal equal to the integral of $(V_T - V_c)/R$ (which actually would be an error angle). If V_c equals V_T, there will be no error due to the vehicle's rotation while it is traveling over the earth, and the platform will stay horizontal at all times. Since the computed input results from Schuler tuning, the basic principles of Schuler tuning are described below and should be thoroughly understood before proceeding.

Accelerometers and Accelerations

There are two types of forces that can cause a body to move–acceleration forces and field forces. It is important to note that an accelerometer cannot distinguish between these two forces. (Accelerometers are discussed in chapter 10 of Aviation Fire Control Technician 3 and 2.) Newton's second law of motion describes acceleration force thus: If a body is acted upon by a force, the product of the acceleration (a) and the mass (m) of the body is proportional to the force (f); $(f = ma)$. The most common field force is gravity. This force



PLATFORM GYRO-VECTOR ORIENTATION



PHYSICAL ORIENTATION

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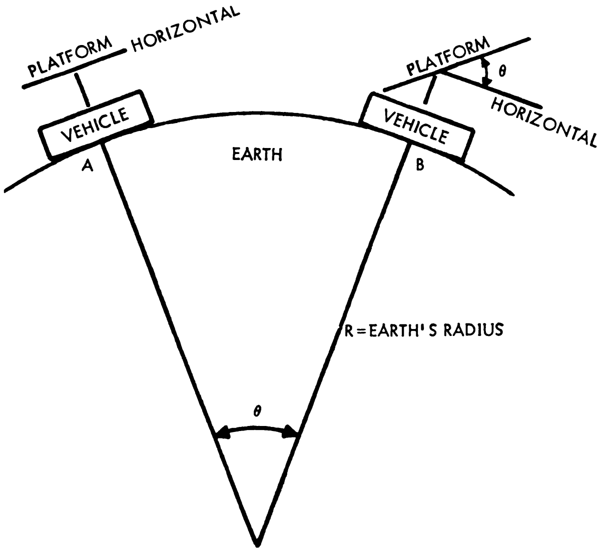
Figure 12-3. –Platform control components and gyro vector orientation.



AQ. 228
Figure 12-4. –Vehicle motion in relation to a space stabilized platform.

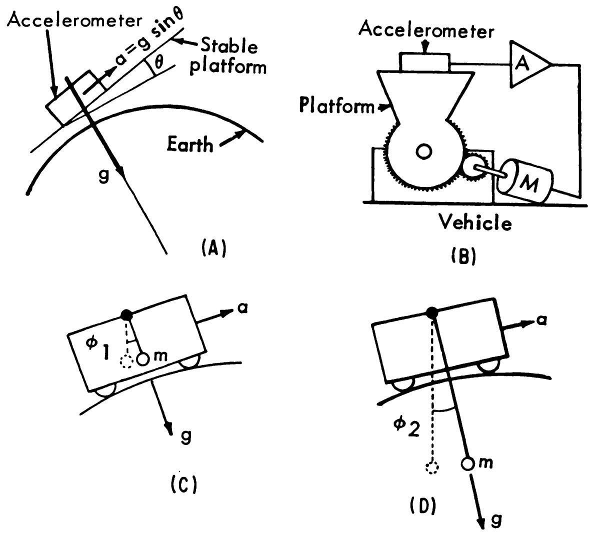


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Figure 12-5. –Basic ideas of Schuler tuning.

is represented by the formula (f = mg). The term (g) represents gravitational acceleration, 32.17 ft per sec per sec–the acceleration with which a body falls freely toward the earth's surface, neglecting air friction.

It should be understood that the accelerometer will provide no output while it is moving at a constant velocity and its sensitive axis is perfectly horizontal. But if the sensitive axis should become misalined, gravitational acceleration will result in a force which displaces the mass and causes the accelerometer to give an erroneous indication of the vehicles acceleration.

SHULER TUNING

Schuler tuning is used in most inertial navigation systems. It maintains the stable platform in an orientation that is perpendicular to the earth's gravity. It also reduces the long term errors, described later, resulting from certain imperfections in the instruments.

To understand why Schuler tuning was developed and how it operates, consider first some of the problems involved in maintaining a stable platform perpendicular to the earth's gravity. For simplicity at this point, consider the earth to be spherical, but nonrotating. A stable platform bearing an accelerometer is shown with respect to the earth in figure 12-5. If the platform is stationary but tilted, as shown (fig. 12-5(A)), gravitational acceleration will cause the mass in the accelerometer to move to the left and produce an output (g sin θ) simulating acceleration to the right. The platform can be leveled automatically if the accelerometer output drives the motor M (fig. 12-5 (B)), which rotates the platform through a gear train. The motor turns until the output from the accelerometer is zero, when the platform angle θ is also zero.

Now assume that the platform is uniformly accelerated to the right. The mass in the accelerometer will again move to the left; and the output of the accelerometer, after amplification, will drive the platform away from the true level position to a new position where there is zero motor voltage. The action of the accelerometer is exactly the same as that of a pendulum; if accelerated along the earth's surface, they both give an erroneous indication of the vertical.

Professor Schuler of the University of Göttingen solved this problem, in principle, in the nineteenth century. He considered the case of a pendulum mounted on a moving body, as shown in figures 12-5(C). The vehicle has a pendulum of mass (m) hanging from a pivot. When the vehicle is accelerated, the pendulum lags by an angle ϕ, as shown. In figure 12-5 (D), a longer pendulum is used. For any given acceleration, the angle of lag ϕ_2 is less than ϕ_1 in figure 12-5 (C). If the pendulum is made longer and longer, the angle of lag becomes less and less. If the pendulum could have its bob at the center of the earth, the angle of lag would be zero and the bob would not move. This is Schuler tuning.

Such a pendulum would have to have an effective length equal to the radius of the earth, approximately 4,000 miles, and a period of 84.4 minutes.

The formula for the period of a pendulum is

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where

T = period in seconds
l = length in feet
g = 32.17 ft per sec per sec

A pendulum with a period of 84.4 minutes can be simulated with electromechanical elements. Taking the output of the accelerometer and integrating it twice before it actually controls the platform provides, essentially, a Schuler-tuned platform. This is shown in figure 12-6. To prove that this loop has an 84.4-minute period and is, therefore, Schuler tuned, tilt the platform very slightly and observe the following events:

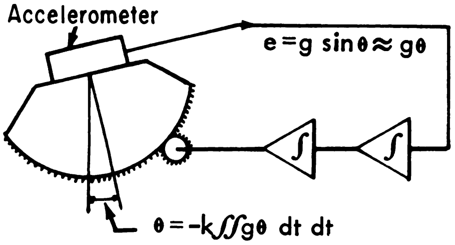

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Figure 12-6. –A Schuler-tuned platform.

An accelerometer mounted on a platform yields a signal proportional to the tilt angle of the platform (assuming that there is no linear motion of the platform). The output of the accelerometer is

$$e = g \sin \theta$$

For very small angles, the sine of the angle is very nearly equal to the angle in radians; therefore,

$$e = g\,\theta$$

The angle θ through which the platform moves to correct the tilt is proportional to the double integral of the accelerometer's output,

$$\theta = -k \iint g\theta \, dt\, dt$$

where

k = constant

Differentiating both sides of this equation twice yields the differential equation

$$\frac{d^2\theta}{dt^2} + kg\,\theta = 0$$

A solution to the differential equation is

$$\theta = A \sin(\sqrt{kgt})$$

where

A = constant

Since a sine function is involved, the platform is evidently going to oscillate because it was disturbed–this oscillation is very slow. To find the frequency or period of the sine function let

$$\sqrt{kg} = \omega$$

and the following are known relationships

$$\omega = 2\pi F = \frac{2\pi}{T}$$

Therefore

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{kg}}$$

or

$$T = 2\pi\sqrt{\frac{1}{kg}}$$

Now, if we let k = 1/R, where R = 4,000 miles (the radius of the earth), the period T will be equal to 84.4 minutes.

The platform will actually be moved very slowly in a direction to correct the slight erroneous tilt, but it will overshoot and move back. The Schuler loop, therefore, is oscillatory. Once disturbed, the platform continues to oscillate about the vertical like an undamped pendulum. The associated oscillations are called Schuler oscillations. However, proper initialization and accurate components keep these oscillations very small. In fact, some of the inaccuracies which would normally result in large errors after a long period of time are averaged out by the oscillations and result in very little long term error.

Unlike the usual pendulum system, the Schuler-tuned system is not disturbed by the vehicle's accelerations. Recall that the second integral of acceleration is distance traveled; therefore, as shown in figure 12-6, the amount that the platform rotates, θ, as the vehicle moves over the earth is directly proportional to the distance traveled. Consequently, the platform rotates just enough to remain perpendicular to the earth's gravity as the vehicle moves over the earth. In other words, it acts as if it were a pendulum with its bob at the center of the earth.

SCHULER LOOP

Figure 12-7 contains both a functional and a mathematical diagram of a Schuler loop. For simplicity, only the north loop is shown. Two such loops, one for north and the other for east, are required for an inertial system. The accelerometer in the north loop senses north-south accelerations; however, the gyro in the north loop senses east-west angular rates—the vehicle's angular movements around the east-west axis. (See fig. 12-3.)

By convention, the accelerometers and gyros are named according to the direction of their input axes; and the inertial or Schuler loop takes the name of its accelerometer. The north loop contains the north accelerometer and X (east) gyro, while the east loop contains the east accelerometer and Y (north) gyro.

Refer to figure 12-7. True acceleration is a_T due to the vehicle's accelerating. An acceleration, $g\theta$, called gravity feedback, is also sensed by the accelerometer when the platform is not perfectly level. It is actually gravitational acceleration g (32.17 ft per sec per sec) times the very small tilt angle θ (probably in milliradians).

It has previously been stated, that the platform could be maintained level by torquing it with a signal proportional to $-V_c/R$. Figure 12-7 shows how this is done. The integrated accelerometer output, V_c, is multiplied by 1/R to obtain a signal porportional to $-V_c/R$. This signal torques the X (east) gyro to cause it to precess and provide a θ pickoff output through the azimuth resolver to the platform pitch torquer. This, in turn, causes the platform to be torqued through an angle proportional to the distance traveled. In other words, the platform actually integrates the computed angular rate $-V_c/R$ to produce an angle.

V_{co} and P_{co} are both inputs to the system, but only V_{co} has any effect on the Schuler loop. For this explanation, V_{co} was assumed to be zero. Another input (not shown in fig. 12-7) that is sensed by the gyro input ϕ axis, is caused by normal flight and combat maneuvers; that is, the angular rate of such maneuvers is sensed by the gyro, causing it to precess and to provide an output through the azimuth resolver to the pitch torquer. The platform torquer responds to these signals, keeping the platform level.

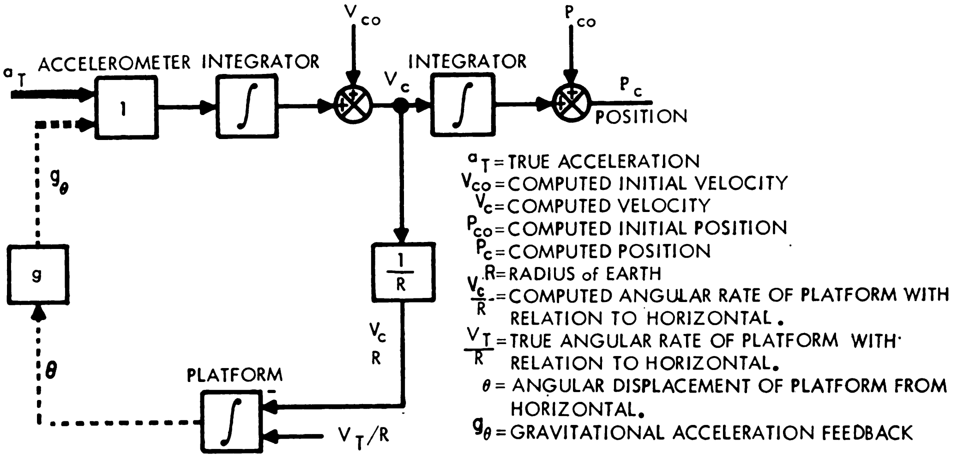
The gyro input ϕ axis also senses V_T/R which is the vehicle's true angular rate due to the vehicle remaining horizontal as it moves over the earth. V_c/R must be equal to V_T/R; if it is not, the platform will not remain level. The sources and effects of such errors are described later.

CORRECTION TERMS

This explanation of inertial navigation has glossed over several important correction terms by assuming a spherical, nonrotating earth. A basic understanding of system operation can be attained without considering these terms. Nevertheless, they are essential for system accuracy and are briefly described.

Correction for Altitude and Earth's Radius

It has been stated that the stable platform is kept level by rotating the platform at the rate V_c/R. This would be acceptable if the earth were a sphere and the vehicle stayed at


a_T
ACCELEROMETER
INTEGRATOR
V_{co}
V_c
INTEGRATOR
P_{co}
P_c
POSITION
1
g_θ
g
θ
$\frac{1}{R}$
$\frac{V_c}{R}$
PLATFORM
V_T/R
a_T = TRUE ACCELERATION
V_{co} = COMPUTED INITIAL VELOCITY
V_c = COMPUTED VELOCITY
P_{co} = COMPUTED INITIAL POSITION
P_c = COMPUTED POSITION
R = RADIUS of EARTH
$\frac{V_c}{R}$ = COMPUTED ANGULAR RATE OF PLATFORM WITH RELATION TO HORIZONTAL.
$\frac{V_T}{R}$ = TRUE ANGULAR RATE OF PLATFORM WITH RELATION TO HORIZONTAL.
θ = ANGULAR DISPLACEMENT OF PLATFORM FROM HORIZONTAL.
g_θ = GRAVITATIONAL ACCELERATION FEEDBACK

MATHEMATICAL DIAGRAM

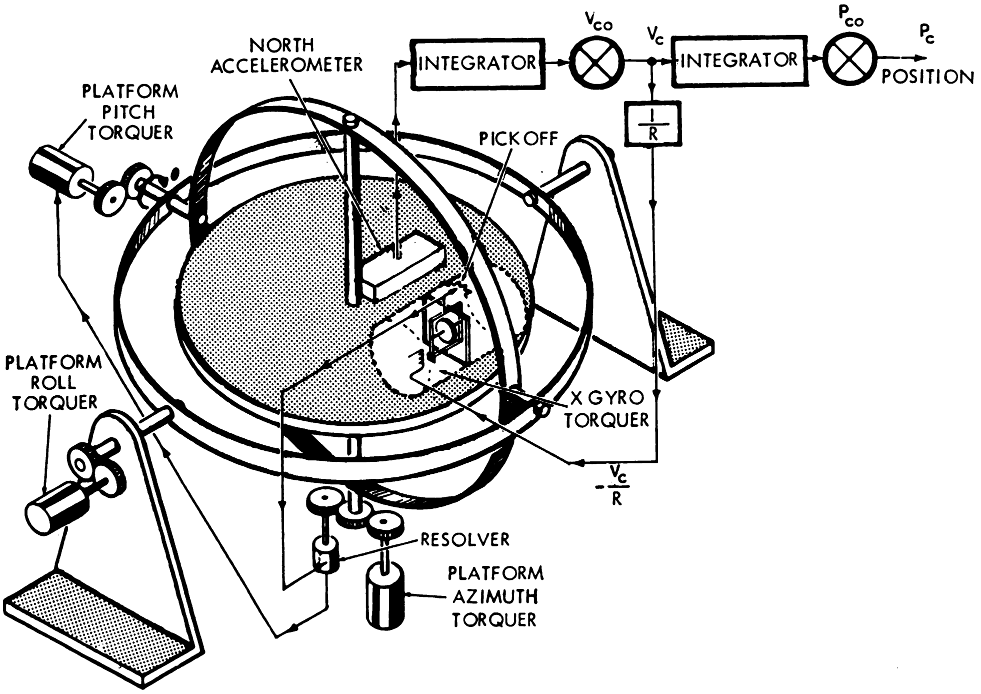


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Figure 12-7. –The north Schuler loop, functional diagram.

the surface of the earth. Since neither of these conditions is met completely, the value of R must be modified to allow for the ellipticity of the earth and for the vehicle's altitude. The new rate of platform rotation required to compensate for these deviations is V_c/R_i; where R_i is the correct instantaneous earth radius. In other words, the 1/R term in figure 12-7 is computed continuously as the vehicle's altitude and latitude change. The instantaneous value $1/R_i$ can be expressed by the series formula:

$$\frac{1}{R_i} = \frac{1}{R_p}\left[1 - \frac{e \cos L_i}{R_p} \cdot \frac{h}{R_p}\right]$$

where Rp is the earth's radius at the pole, e is the correction for the ellipticity of the earth, L_i is the instantaneous latitude, and h is the vehicle's altitude.

Coriolis Correction

Accelerometers actually measure acceleration with respect to inertial space. Up to this point, a nonrotating earth has been assumed; therefore, acceleration due to the earth's rotation has been ignored. The difference between the accelerations measured in a vehicle moving over a nonrotating earth and the accelerations measured in the same vehicle moving over a rotating earth is called Coriolis acceleration. Coriolis acceleration occurs because a straight path with respect to the earth becomes a curved path in space when the earth rotates. A curved path can be achieved only by an acceleration force acting at right angles to the flightpath, and the accelerometer detects this acceleration. Since the magnitude is a function of the vehicle's instantaneous latitude and the earth's rotation, it is continuously computed and subtracted from the accelerometer output.

Correction for Earth's Rotation

Another correction due to the earth's rotation is required. Since the platform gyros sense rates about the three input axes, they will sense the earth's rotation. The earth's rotation is constant; thus, the compensation rate about each axis is a function of the vehicle's position. A correction rate for each axis is continuously computed and added to V_c/R_i. The resultant signal torques the appropriate gyros to maintain the platform level as the vehicle moves over the rotating earth.

ERRORS IN NAVIGATION

For completeness, more mathematics will be used in the description of system errors; however, system errors can be understood without a thorough knowledge of the mathematics used. The sources of the errors will be described first, and then the major system error due to each source will be considered.

Sources of Errors

Errors in the initial conditions affect the accuracy of the system. There are four initial conditions that must be set before the system can navigate accurately. Two are initial conditions for computation-the initial position, P_{co} and the initial velocity, V_{co}. Their associated errors are initial position error, $(E)P_{co}$, and initial velocity error $(E)V_{co}$. The other two are platform initial conditions. Since the platform must be perfectly level, there is probable initial tilt error, θ_o, in each axis; and since the platform must have one axis pointed exactly north and the other east, there is a probable initial alinement error ψ_o to north.

There are two major component errors-accelerometer bias, Δ_a, and gyro drift rate, $\dot{m}$. They are caused by mechanical imperfections of the components. Accelerometer bias is an erroneous output from the accelerometer when the platform is perfectly level and the vehicle is not accelerating. Gyro drift is an output from the gyro θ pickoff which was not caused by the rotation of the earth or by any movement of the vehicle over the earth's surface. Gyro drift is the more important of the two.

Effect of Errors

The error in the computed velocity, $(E)V_c$, can be computed for each of the errors mentioned above. The equations which give the $(E)V_c$ for each error individually are included and are plotted in figure 12-8. They were derived by using differential equations, and their derivation is considerably beyond the scope of this course.

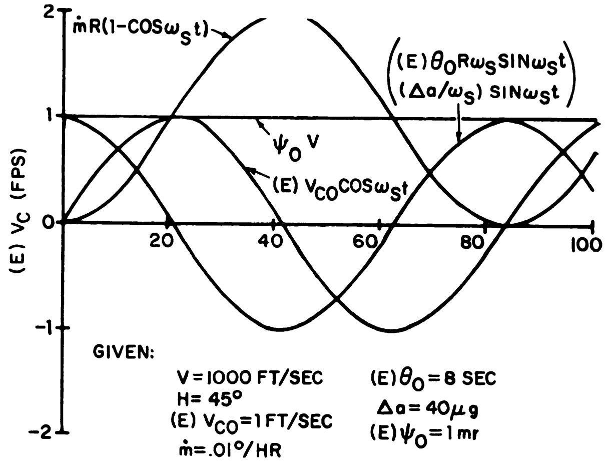

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Figure 12-8. –System velocity errors as a function of time (minutes).

Error in computed velocity, $(E)V_c$, due to an error in initial velocity, $(E)V_{co}$, is

$$(E)V_c = (E)V_{co} \ \mathrm{COS}\ \omega_s t$$

where

$$\omega_s = \sqrt{\frac{g}{R}}$$

Error in computed velocity due to gyro drift rate $\dot{m}$ is

$$(E)V_c = \dot{m}\, R\, (1 - \cos \omega_s t)$$

Error in computed velocity due to initial platform tilt error θ_o is

$$(E)V_c = \theta_o\, R\, \omega_s \sin \omega_{st}$$

Error in computed velocity due to accelerometer bias Δ_a is

$$(E)V_c = (\Delta_a / \omega_s) \sin \omega_s t$$

Error in computed velocity due to true vehicular acceleration a_T is

$$(E)V_c = a_T (0)$$

The last equation was also derived using differential equations and is important because it shows that there is no velocity error due to vehicular acceleration. All the errors are due to erroneous initial conditions and to component errors. Since the two loops are identical, the errors are the same for the north and east Schular loops.

Figure 12-9 shows that the velocity error due to an initial platform alinement error, ψ_o, is the error in resolving the vehicle's velocity, V, through the angle $H - \psi_o$ instead of H. The velocity errors are different in the north and east directions and are functions of the heading H. Assuming ψ_o to be a very small angle, the velocity errors are

$$(E)V_{cN} = V_{NT} - V_{NP} = \psi_o V \sin H$$

$$(E)V_{cE} = V_{ET} - V_{EP} = \psi_o V \cos H$$

where

$(E)V_{cN}$ and $(E)V_{cE}$ equal computed north and east velocities.

V_{NT} and V_{ET} equal true north and east velocities.

V_{NP} and V_{EP} equal platform north and east velocities.

These two equations can be combined into an error, $(E)V_{c1}$, which is perpendicular to V. That is,

$$(E)V_{c1} = \sqrt{(E)V_{cN}^2 + (E)V_{cE}^2}$$

$$(E)V_{c1} = \psi_o V$$

This equation, plotted in figure 12-8, becomes a straight line at 1 fps. That is, since vehicle velocity is given at 1,000 fps and ψ_o is given as 1 milliradian, 1000 x .001 = 1 fps.

The computed position error, $(E)P_c$, can be found for each type of error by integrating the velocity error equation. These errors are plotted in figure 12-10. However, $(E)P_c$, due to initial position error $(E)P_{co}$, is equal to the initial position error; that is,

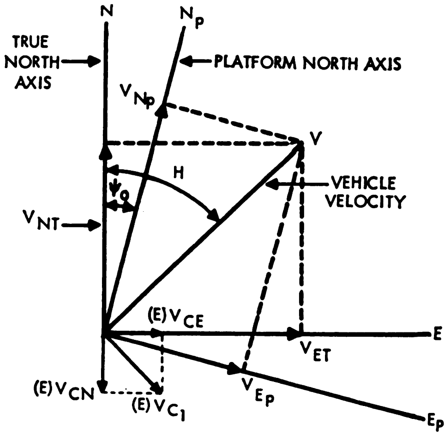

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Figure 12-9. -Effect of platform alinement error.

$$(E)P_c = (E)P_{co}$$

and $(E)P_{co}$ is assumed to be zero in figure 12-10. All other fixed values in figure 12-10 are the same as those given in figure 12-8. As plotted in figure 12-10, an error in computed position $(E)P_c$ due to an error in initial velocity is

$$(E)P_c = \left[(E)V_{co}/\omega_s\right] \sin \omega_s t$$

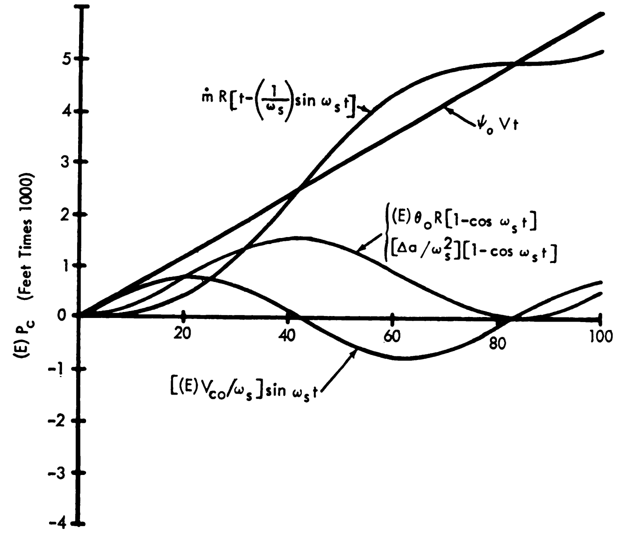

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Figure 12-10. -Systems position errors as a function of time (minutes).

Error in computed position due to a gyro drift rate $\dot{m}$ is

$$(E)P_c = \dot{m}R\left[t - \left(\frac{1}{\omega_s}\right)\sin \omega_s t\right]$$

Error in computed position due to platform tilt error θ_o is

$$(E)P_c = \theta_o R\left[1 - \cos \omega_s t\right]$$

Error in computed position due to accelerometer bias Δ_a is

$$(E)P_c = (\Delta_a/\omega_s 2)\left[1 - \cos \omega_s t\right]$$

The computed north position error $(E)P_{cN}$ due to a platform initial alinement error is

$$(E)P_{cN} = \psi_o (V \sin H)t$$

and, the computed east position error $(E)P_{cE}$ due to ψ_o is

$$(E)P_{cE} = - \psi_o (V \cos H)t$$

Combining these two errors produces an error perpendicular to the path traveled, $(E)P_{c1}$ where

$$(E)P_{c1} = \psi_o V t$$

The first five position error equations are both north and east errors, independent of the vehicle's heading; that is, each equation applies to both the north and east Schuler loops. The next two equations are north and east errors, because they are functions of heading. The first five equations and the last equation are plotted in figure 12-10.

Figures 12-8 and 12-10 clearly illustrate one of the major advantages of inertial navigation. Of all the sources of velocity error, only two result in position errors that increase with time—platform initial azimuth alinement error ψ_o and gyro drift rate $\dot{m}$. Gyro development has reduced drift rates to approximately 0.01° per hour, whereas a platform initial azimuth misalinement of about 2 milliradians is practical.

INITIALIZATION OF INERTIAL NAVIGATION SYSTEMS

The following is a description of the techniques and problems involving leveling and alining inertial navigation systems. Such problems range from the most simple case to the one which is of primary concern to Navy aircraft; that is, the problem of initialization on board an aircraft carrier. While leveling and alining are related and, in some cases, dependent upon each other, they are treated separately at the beginning to simplify the discussion.

Before continuing, some of the terms used frequently are defined briefly:

Leveling—the process of bringing the stable platform to a position where the accelerometers do not sense any gravity components.

Alining—the process of bringing the sensitive axes of the platform into a known position in azimuth.

Initialization—the process of bringing the inertial system to a set of initial conditions from which it can proceed with the navigation process. This includes leveling, alining, setting of initial velocity and initial position, and all additional computations required to start the navigation. In the following discussion, the term will be used to mean leveling and alinement; but keep in mind that these other initial conditions are implied. They receive less emphasis because they are easily accomplished in the computer.

Slaving—the process of torquing the system gimbals to a position defined by some reference which is external to the system.

Gyrocompassing–the process of self alinement whereby the system achieves azimuth orientation from its own sensors, in the manner similar to a conventional gyrocompass.

The effects of tilt error and azimuth error at the beginning of navigation were examined previously, and a plot of system position errors as a function of time for several values of these initial condition errors was shown in figure 12-10. It is evident from an examination of these curves and from reading the description of the errors, that failure to achieve the proper initial conditions is disastrous to navigational accuracy.

The initialization technique which most of us would first consider is probably one of slaving. The platform gimbals could be rotated to position defined by some external reference in the same manner as a gun mount is slaved to the stable element of a ship. This method is useful and can be applied to our problem; however, the accuracies we require cause it to be a more critical operation than gun mount stabilization. In addition, while it is quite simple in concept, slaving is more complicated in terms of additional equipment required.

In self initialization, no external directional references are used. The system orients itself by means of computations performed on the outputs of its own sensors–gyros and accelerometers. This method is less complicated in terms of external equipment, but more complicated in concept. The following paragraphs are devoted primarily to a description of self-initialization techniques and the problems and errors associated with these techniques.

SLAVING IN A STATIONARY LOCATION

The most simple environment for the initialization of an inertial system is a known, fixed position on the earth. All initial conditions, including level and azimuth, could be available from external sources. A typical example of this environment is a missile launching site. Here, level and azimuth information can be transferred to the platform by optical and electrical transfer methods. These methods require installation of equipment to mechanize this transfer and are best suited to the missile launching situation.

SELF INITIALIZATION IN A STATIONARY LOCATION

Still simple, but not so well suited to external slaving, is the environment of a known, stationary position not sufficiently fixed to permit installation of slaving equipment. An example of this environment is an aircraft which alines at any of a number of stationary positions in or about the hangar and flight apron. This discussion is started with self initialization for systems in this environment, from which it can be expanded to encompass the more complex environment of an aircraft carrier. An additional simplification will be introduced here by discussing leveling separately from alinement. Within certain limits, leveling can be accomplished independent of azimuth alinement; and it can be seen later, in the discussion of gyrocompassing, that it is desirable to level the platform before attempting to gyrocompass.

Briefly review the sensors and connections available on the inertial platform. It contains the accelerometers, which sense acceleration and consequently gravity; gyros, which sense angular rates; a gyro-torquing coil, as part of each of the three gyros on the platform, to torque each gyro individually; and gimbal-torquing motors to torque the platform. The gyro-servo combination is capable of accepting electrical inputs from external sources to torque the platform.

An electrical signal applied to the gyro torquer will cause the gyro to produce an output signal to the platform-torquing servomotor which, in turn, causes the platform to rotate continuously until that signal is removed. All self-initialization schemes make use of this characteristic of the gyro-servo combination. They all operate on some modification of the basic acceleration-leveling scheme, which will be described first.

Acceleration Leveling

In its most simple form, leveling is accomplished by taking the electrical output of the accelerometer and applying it to the gyro torquer. As long as the platform is not level, the accelerometer has an output due to the force of gravity. When this accelerometer output is sent to the gyro torquer, it causes the platform to rotate and thus reduce the signal from the accelerometer. When the accelerometer is leveled, it no longer has an output.

Thus, the gyro no longer has an input; and the platform remains in this leveled position.

The speed with which this mechanization can level the platform is a function of the gain of the amplifier. Higher gains will cause the platform to torque more rapidly. However, due to the presence of noise in the output of the accelerometer, there are certain limitations to the amount of gain which can be used, If the gain is very high, the platform will respond rapidly to small variations in the output of the accelerometer. A theoretical acceleration-leveling arrangement is shown in figure 12-11.

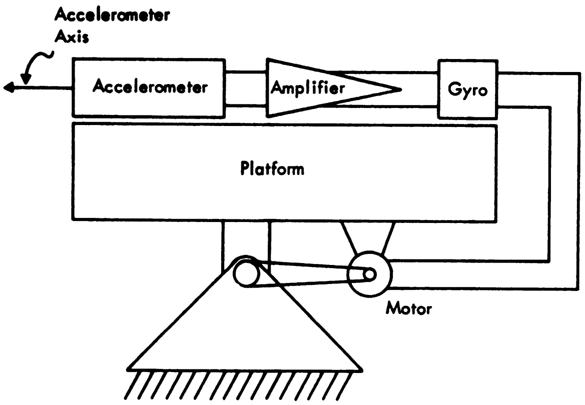

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Figure 12-11. -Functional diagram of acceleration leveling.

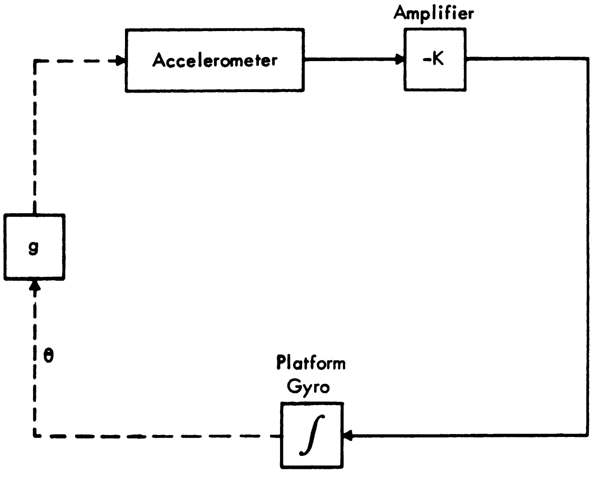

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Figure 12-12. -Mathematical diagram of acceleration leveling or first order leveling.

Figure 12-12 is a mathematical schematic diagram of this theoretical arrangement. All electrical connections are indicated by solid lines and all physical inputs by dotted lines. For example, the gyro output is a physical quantity; i. e., the angle between the platform and the horizontal. When this angle is not zero, it causes gravity to be coupled into the accelerometer input, as indicated by the block labeled g. This physical input to the accelerometer box causes an electrical output from the accelerometer, which is amplified (-K is the amplifier gain) and used to torque the gyro. Thus we have the closed loop system. When the platform is level, there is no gravity coupling to the accelerometer; and the loop is in a steady state.

Second Order Leveling

As previously explained, the navigational function of the platform requires that the acceleration be integrated to obtain velocity before it is fed to the gyro torquer. It would be desirable to maintain this configuration for the leveling loop so there would be a minimum of changes between the leveling system and the navigating system. (See fig. 12-7.)

It would seem that this loop would also level the platform, since the accelerometer output is applied to the gyro torquer through the integrator. Unfortunately, this is not exactly true. The nature of the Schuler loop causes it to act as an undamped pendulum which never reaches a level condition, but continues to oscillate about that position. Another drawback to leveling in this manner is the sluggish nature of this loop, due to the very low gains. The basic period of this loop is 84 minutes-primarily due to the low gain of 1/R. Since the purpose here is to establish a vertical, and not to navigate, this term is no longer required to be 1/R, but can take on any value desired. In this case, it is desirable to make it large in order to level the platform rapidly. Having altered the sluggish nature of the platform, it is changed to act like a damped pendulum by feeding the integrator output to the accelerometer input, This causes the oscillating platform to come to rest in a level position. The mathematical diagram of this arrangement is shown in figure 12-13. The gain -K2 is larger than 1/R. The diagram shows, too, that the initial tilt error θ_0 also causes the accelerometer to sense gravity and that the platform tilts until its output θ cancels θ_0. At that time the accelerometer will be level.

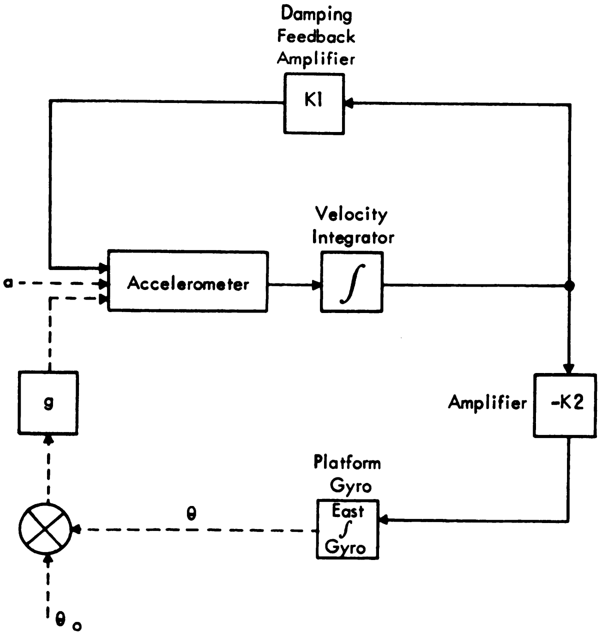

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Figure 12-13. –Second order leveling loop.

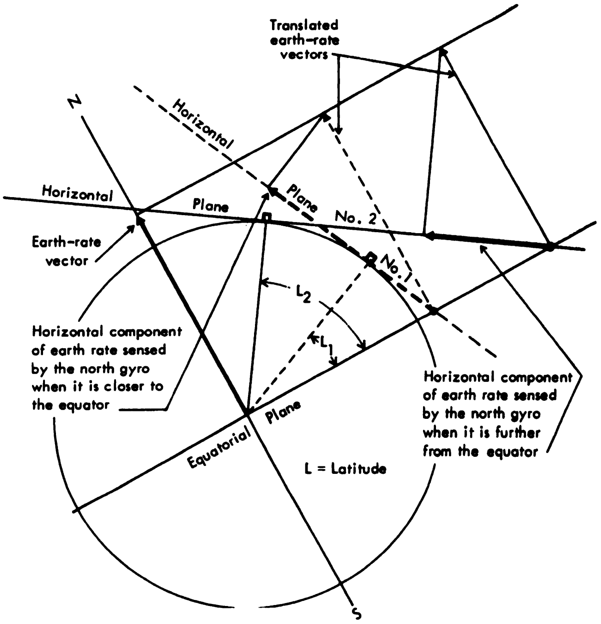

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Figure 12-14. –Horizontal component of earth rate.

Gyro as a Rate Detector

Before gyrocompassing is described, the rate measuring capability of a gyro should be clarified. The gyro detects rates about its input axis. The platform gyro-vector orientation is shown in figure 12-3. If the axis of the rotation is not parallel to the gyro input axis, the gyro will not sense the entire rate but only some portion of it which is proportional to the angle between the rate rotation axis and the gyro input axis. This can be easily represented by using vectors to describe the rates. A vector representation of a rate will be directed along the axis of rotation, with its length proportional to the rate and its direction according to the right-hand rule which is similar to the one used in describing magnetic fields about a wire. If the right hand is wrapped around the axis with the fingers indicating the direction of rotation, the thumb points in the direction of the rate vector. Rate components of this vector along other axes at angles to the rotation axis will be equal to the rate times the cosine of the angle between the axes. Figure 12-14 shows how this works for the earth-rate component in the horizontal plane. This shows that a gyro with its input axis in the horizontal plane and pointed north will sense a rate equal to earth-rate times the cosine of latitude; that is, when the north gyro is at the equator, it senses the entire earth rotation rate; but when it is at the north pole, it senses none.

Gyrocompassing

With this concept in mind, a discussion of azimuth alinement by a method known as gyrocompassing should follow. It is so called because the basic technique is exactly the same as the one used in a conventional ship's gyrocompass. The vector relationship for earth rate in the horizontal plane was shown in figure 12-14. Now examine figure 12-15, which is a top view of the horizontal plane. The coordinate axes labeled X and Y are the principal axes of a platform misalined from north by an angle ψ. Each of these axes is the sensitive axis of a gyro: Y is the north gyro and X is the east gyro. (As mentioned previously, the north gyro has its input axis running north-south and would sense the east-west rotation of the earth.) First simplify the earth-rate vector by letting Ω_{IE} COS L = Ω_N. Then, resolving it into the X and Y axes gives the two components shown, Ω_N COS ψ along the north gyro axis and $-\Omega_N$ sin ψ along the east gyro axis. It is desired to rotate the platform in azimuth until

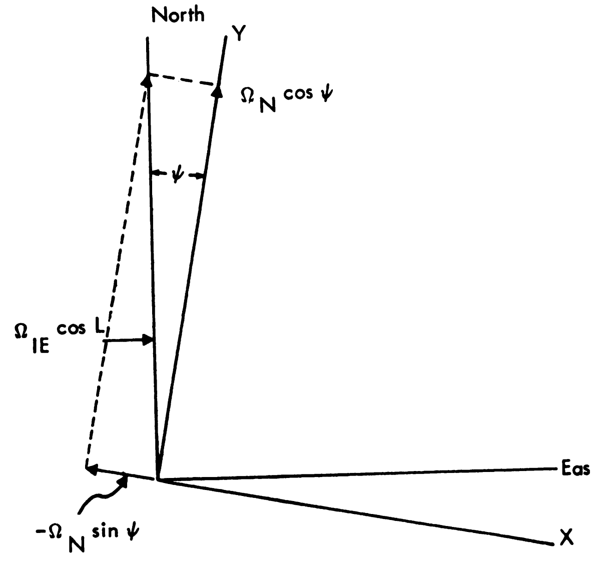

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Figure 12-15. –Components of earth rate in the horizontal plane.

ψ is zero. At that time the two components will be Ω_N along the north gyro axis and zero along the east gyro axis. This is a situation made to order for a servomechanism approach. The east gyro is an error sensor which detects zero error when the platform is in the desired position. Practically all the necessary components are in the second order leveling loop. If the second order leveling loop is not oriented with the east gyro axis pointed exactly east, this gyro will pick up an earth-rate component. For the leveling loop to reach a steady state, this gyro input must be canceled.

The gyrocompassing feature is added to the second order leveling loop in figure 12-16. The integrated acceleration does not reach zero, but rather a value equal and opposite to the earth-rate input to the gyro. This value can be used as the error signal for azimuth alinement. The signal is amplified with a gain of -K3, and used to torque the azimuth gyro and, consequently, the platform; that is, the azimuth gimbal torquer moves through an angle ψ until it cancels out the initial alinement error angle ψ_0. As the east gyro axis becomes perpendicular to the earth-rate vector, the output of the velocity integrator drops to zero; and the platform stops torquing when the east gyro axis is pointed directly east and the platform is level.

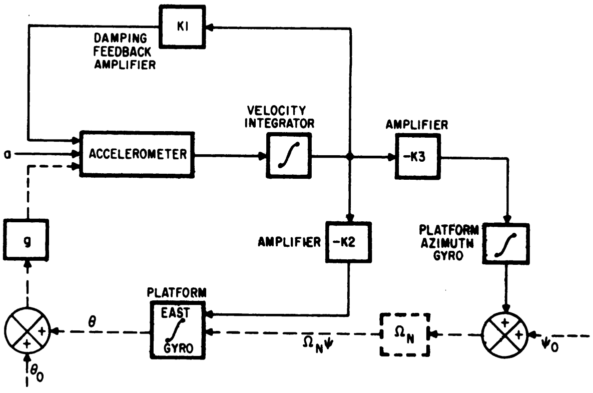

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Figure 12-16. –Gyrocompassing loop.

The azimuth gyro is represented as an integrator with an output of platform azimuth error ψ. Remembering that the sine of a small angle is approximately equal to the angle in radians, the earth-rate input to the east gyro can be simplified; it is shown as $\Omega_N \psi$. When the loop reaches steady state, the east gyro has zero input because ψ is equal to zero; the azimuth gyro has no input because the indicated input to -K3 is zero. In addition, the platform is level because there is no signal feed back through K1.

INITIALIZATION ON A MOVING BASE

At this point there is an established system which alines satisfactorily in a stationary environment. Now go back to the simple first order leveling loop (fig. 12-12) and examine its performance on an accelerating base such as an aircraft carrier.

Acceleration Leveling

Leveling was accomplished by nulling the accelerometer output. If the platform is on a vehicle which is accelerating (an aircraft carrier in a turn), there will be an input to the accelerometer in addition to the gravity terms caused by tilt. These will cause outputs, which look like tilts, at the level position of the accelerometer; that is, an acceleration of 0.001 g will look like a tilt of 3.44 minutes of arc. The simple acceleration leveling scheme will rotate the platform until the accelerometer has zero output, whether these outputs are from tilts on accelerations of the base. The 0.001-g input mentioned will cause a tilt error of 3.44 minutes of arc. An aircraft carrier in a turn of 0.5 degree per second at 25 knots is accelerating at a rate of 0.11 g toward the center of the turn. It can be seen that this causes an intolerable tilt error. One way to eliminate this problem is to introduce a term which compensates for the acceleration. This would require some independent device to measure the acceleration. The achievement of an external measure of acceleration without the use of another inertial system presents so many problems that first order leveling on the moving base is abandoned, since there are easier ways to solve the problem.

Second Order Leveling

The second order leveling loop also provides leveling problems during accelerations. The velocity integrator output changes during accelerations and disturbs the platform level through the K1 feedback. In addition, the aircraft carrier's velocity over the earth introduces rate inputs to the gyros which cause steady state platform tilts. The tilts associated with these effects are too large for satisfactory platform initialization and must be removed by some form of compensation. Both of the disturbing errors are velocities; therefore, they can be compensated by introducing velocity from an external source, such as the ship's electromagnetic log (EM log).

The ship's EM log is a speed measuring device which makes use of Lenz's law to measure the speed of the ship. Lenz's law defines the nature of electric currents generated in conductors moving in magnetic fields. In the case of the EM log, a sensor called the sword is lowered into the water. As sea water (which is a conductor) flows around the sword, a current is induced in the sea water. This current causes a secondary magnetic field which distorts the primary field of the log. Measurement of the field distortion gives an indication of the ship's speed through the water.

The log has two major sources of error: First, it measures only speed through the water; consequently it ignores any ship velocity due to ocean currents; and second, it measures only the local longitudinal component of velocity. As the ship slips sideways in a turn, the alterations in local flow at the log cause it to have errors on the order of 2 to 3 knots.

The reference velocity is introduced as shown in figure 12-17; that is, it cancels the steady state value of platform velocity at the velocity integrator output so that the feedback through K1 and the feed forward through -K2 are nearly zero in a steady state. The rate due to the aircraft carrier's velocity over the earth is computed and used to compensate the level gyros. Neglecting errors in reference velocity, the system levels as accurately as a second order loop at a stationary location.

Examine the effects of errors in the reference velocity. There are two major types of error, and they cause two very different problems. The constant error, which is due to ocean current and EM log bias, causes a steady state tilt error just as a gyro drift rate does. This error would not substantially change the gains used in leveling at sea. The other source of reference velocity error is the transient and oscillatory error in the EM log. The most troublesome error in the log is the inaccuracy of its output during a turn. The errors thus introduced to the platform cause it to take up transient tilts with peak values much larger than the steady state errors. Even if the ship is not in a turn, there is continuous oscillatory "noise" on the EM log due to slight wander of the ship about its straight course and to the ship's pitch and roll motion. In order to minimize the transient excursions of level, the gains must be made lower. Making gains lower has the detrimental effect of lengthening the time required to remove initial errors. The gain selection then becomes a compromise between fast elimination of erroneous initial conditions and attenuation of transient errors. This defines the basic problem of alining and leveling at sea, which becomes more severe as azimuth alinement is attempted.

Gyrocompassing

The gyrocompassing loop develops from the second order leveling loop, just as it did on the stationary base. In this case the velocity difference signal is used, through the -K3 amplifier, as the torquing input to the azimuth gyro. The reference rate to the east gyro, through the -1/R amplifier, should compensate for the rate due to velocity of the aircraft carrier and leave the earth-rate error signal as the primary gyrocompassing signal. This loop is shown in figure 12-18.

In figure 12-18, an additional factor has been added to the earth-rate term. This is the

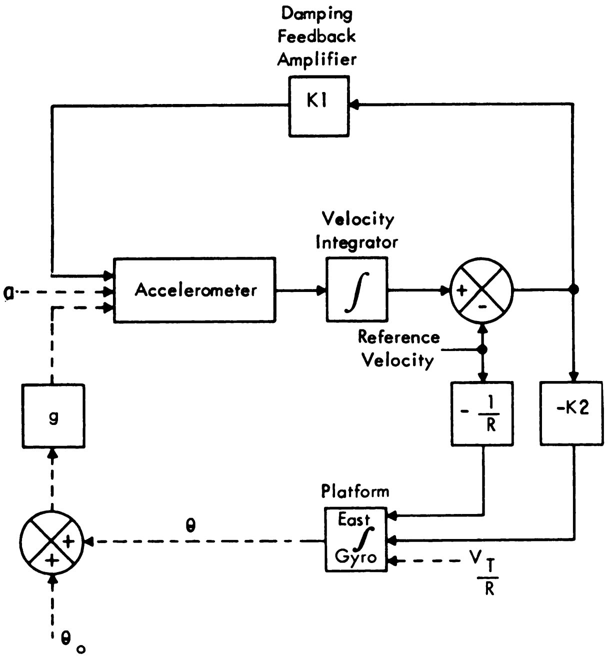

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Figure 12-17. –Second order leveling loop with reference velocity.

V_E/R term, which reflects the additional rate due to east velocity. It has no bearing on steady state error, but it does have the effect of changing the loop gain as a function of east velocity.

The gyrocompassing loop is the same as the one developed previously, with the addition of the reference velocity inputs. The same steady state results hold for this loop. It will level accurately, except for error due to accelerometer bias; and it is not sensitive in level to rate errors to the east gyro. Azimuth accuracy is a function of rate errors to the east gyro; therefore, the bias errors in the reference velocity will add to the east gyro drift in causing azimuth error. The azimuth error is a function of latitude; it will be about 4 minutes for each knot of north reference error in midlatitudes.

The errors just described are steady state errors. Just as in the case of leveling, transient velocity errors are severe problems. Any reference velocity errors appear immediately at the azimuth gyro torquer, so that any errors will cause the platform to be torqued erroneously in azimuth. In order to hold this azimuth error to a small value, the torquer gain -K3 must be kept low. As in the level loop, any reduction of gain increases the time for removal

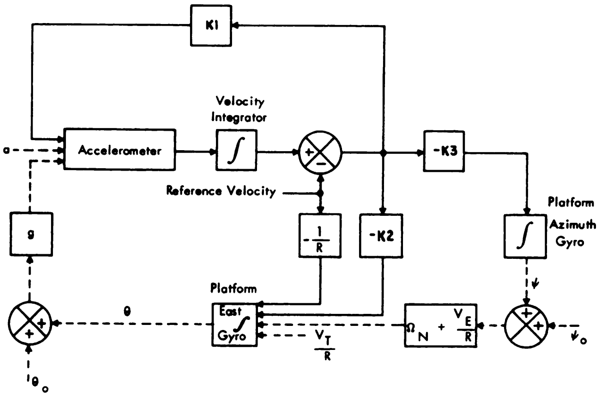

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Figure 12-18. –Gyrocompassing loop with reference velocity.

of initial condition errors. Gains which permit reasonably accurate alinement during turns, using the EM log, require gains low enough that 30 to 45 minutes of alinement time will be required to reduce the initial condition errors to the desired values. Even with these low gains, large turns at the end of alinement can cause intolerably large errors in azimuth.

Inertial Source of Reference Velocity

One method of solving this problem lies in the use of another alined intertial system to supply the reference velocity to the alining system. The problem with the EM log was two-fold: It did not measure all velocities (ship motion), and it was in error during turns. The inertial reference source does not have these drawbacks. It measures all velocities at the point where it is mounted, and it has no errors which are a function of turns. The worst problem of the inertial system is long term bias errors due to platform drift and initial alinement errors. If the inertial system is alined at sea, it will have a bias error equal to EM log bias in its velocity output. However, the errors due to long term biases are small compared to the transient errors; and the accuracy of intertial systems on a short term basis makes these transient errors small. In this respect, the inertial source of velocity holds forth promise of shortening alinement times, but gyrocompassing is still limited in the sea environment because this environment is inherently noiser and requires lower gains to attenuate the noise. At present, the limited factor in the use of inertial reference sources in the distribution of correct reference velocity to points remote from the reference location. Pitch, roll, and yaw motions cause remote parts of the ship to have sizable velocities with respect to the reference location. To realize the full value of an inertial source, these relative velocities must be computed and added to the reference system output velocities. The accuracy with which this can be done limits the maximum gains which can be used.

Rough Leveling

The sea environment adds one more problem to the alinement process. Since platform tilt enters the gyrocompass loop as part of the apparent azimuth alinement error, any initial tilt at the start of gyrocompassing will result in an azimuth response. In fact, the loop is quite sensitive to this tilt, with a peak azimuth transient error reaching as high as 20 times the initial tilt error. At sea, where sea motion causes the vehicle to be oscillating about the vertical, it is difficult to initialize the level accurately. It may be off 3^{o} or 4^{o}, causing a peak azimuth transient of 60^{o} to 80^{o} One way to avoid this problem is to level roughly with the second order loop before starting the gyrocompass torquing. In 2 or 3 minutes the platform can be leveled to less than 10 to 20 minutes-of-arc error. Subsequent gyrocompassing is then easier because of the elimination of the large transient.

Now review the requirements and problems of shipboard initialization. The accelerations of the ship create inputs to both accelerometers and gyros which prevent the techniques of stationary leveling from working properly. These accelerations must be compensated by the introduction of a reference velocity. The EM log is a fairly good source of reference velocity, but it has its largest error during turns–which is also the time of highest acceleration. To reduce these errors, system gains must be made low, resulting in long alinement times. Reference velocity from an inertial system has better characteristics and will permit shorter alinements; however, the sea environment is always a difficult environment for gyrocompassing; and there are practical limits to short alinement even with inertial source of reference velocity. Alinement times of 5 minutes and less will require more exotic methods than gyrocompassing.

PRINCIPLES OF DOPPLER NAVIGATION

A simplified explanation of the Doppler principle as it applies to Doppler radar navigation is presented first to provide the basis for understanding its application in Radar Navigation Set AN/APN-122(V). A general theory of system operation follows, based on the methods employed in the AN/APN-122(V) System. These methods are essentially the same as those used in the AN/APN-122(V) Modified System.

DOPPLER RADAR PRINCIPLES

As opposed to search and acquisition type radar which employs pulse type RF transmission, the Doppler radar employs CW RF transmission in conjunction with the "Doppler effect." It should be remembered that pulse type radar determines distance to target by measuring the period between transmission of a pulse and recipt of the reflected pulse, while the CW Doppler radar senses velocity by measuring a proportional shift in frequency of the reflected signal. This frequency shift is the "Doppler effect." In operation, the airborne CW Doppler radar transmits fixed-frequency, RF signals as two or more narrow beams. The beams are transmitted earthward and displaced laterally and longitudinally at fixed and equal angles. The same airborne set receives a portion of the earth-reflected CW signals, each of which has undergone a Doppler frequency shift due to the Doppler effect. By continuously mixing the received energy with samples of the transmitted energy, followed by electronic detection, velocity proportional difference frequency signals are extracted. These are the Doppler signals, and they contain composite velocity information. Since they are of audiofrequency, they may be amplified, electromechanically or electronically tracked, and compared with pitch, roll, and altitude rate information to derive the individual components of the aircraft's velocity relative to the aircraft axes or relative to the earth's surface.

Doppler Effect

Electronically, the Doppler effect is the apparent increase or decrease in frequency in a received signal resulting from the movement of either the transmitter or receiver, or both relative to each other, or from the simultaneous movement of a combined transmitter-receiver relative to a fixed reflecting surface. Disregarding angular motion for the present, the

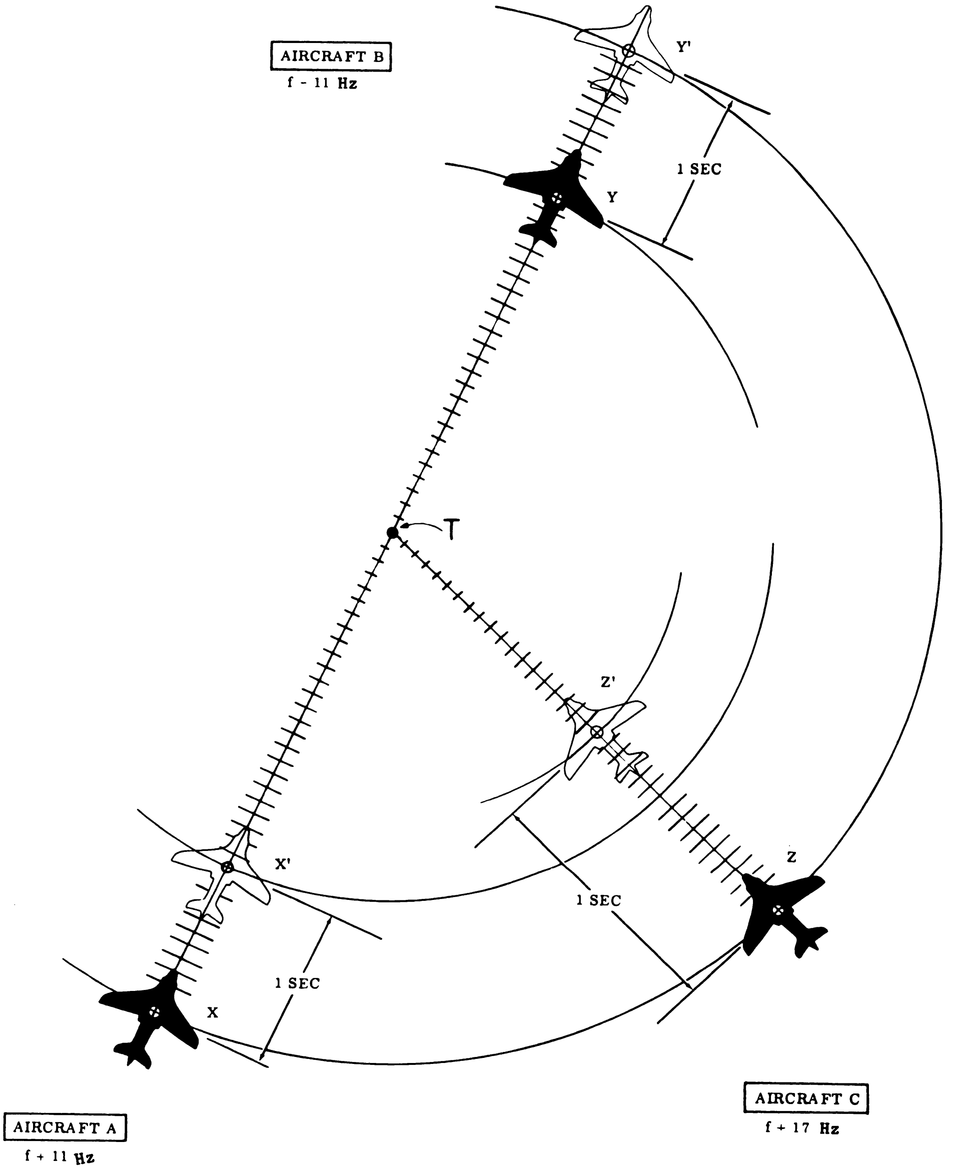

Figure 12-19.—Doppler frequency shift, stationary transmitter, airborne receiver.

magnitude of the frequency shift is directly proportional to the closing or receding velocity along a straight line distance between the transmitter and receiver, or between the combined transmitter-receiver and fixed reflecting surface.

The Doppler effect is best explained with the aid of figure 12-19. Assume three conditions of flight relative to transmitter T, represented on figure 12-19 by aircraft A, B, and C.

Aircraft A—heading on a straight line course toward T and flying at a constant speed of approximately 11 wavelengths per second, covers the distance from point X to X' in 1 second.

Aircraft B—heading on a straight line course away from T and flying at the same constant speed as A, covers the distance from Y to Y' in 1 second.

Aircraft C—heading on a straight line course towards T and flying at a constant speed approximately 1 1/2 times the speed of A, covers the distance from Z to Z' in 1 second.

During all three preceding conditions, transmitter T is transmitting a VHF, CW signal of "f" cycles per second. Therefore, each distance from X to X', Y to Y' and Z to Z' is equal to a specific number of wavelengths at "f" frequency.

Now assume that each aircraft, A, B, and C, is equipped with a relatively broad-band receiver capable of accepting signals at frequencies higher or lower than transmitted frequency "f." During the 1-second interval in which A is flying from point X to X', "f" number of cycles of the signal from T reach point X. Since A is advancing in a straight line towards the signal source, it receives not only the "f" number of cycles it would receive if stationery for 1 second over point X, but simultaneously receives additional wavelengths of the signal en route between point X' and X. Therefore, aircraft A receives a signal which is of apparent higher frequency than that emitted by the transmitter.

The magnitude of the preceding frequency shift is proportional to the speed of the aircraft toward T and inversely proportional to the frequency of the transmitted signal. The direction of frequency shift is dependent on the direction of flight relative to the signal source. The effect of flight direction and speed on the direction and magnitude of frequency shift is illustrated by aircraft A, B, and C on figure 12-19. Since aircraft B is flying away from the signal source at a speed equal to the speed of A, the apparent frequency is lower than the transmitted signal but equal in magnitude to the apparent frequency received by A. Since aircraft C is flying in the same direction but approximately 1 1/2 times the speed of A, the frequency received by C is also apparently higher than the transmitted signal but greater than that received by aircraft A. The apparent frequency shift is the Doppler effect.

When an aircraft sets its heading toward a fixed ground transmitter but experiences drift which, if not corrected, results in a heading as illustrated in condition B (fig. 12-20), the Doppler frequency shift is proportional to the amount of drift, as illustrated.

The following conditions on figure 12-20 are assumed:

Aircraft A–flying with zero drift and headed straight toward transmitter T.

Aircraft B–flying at the same speed as A but drifting past the transmitter.

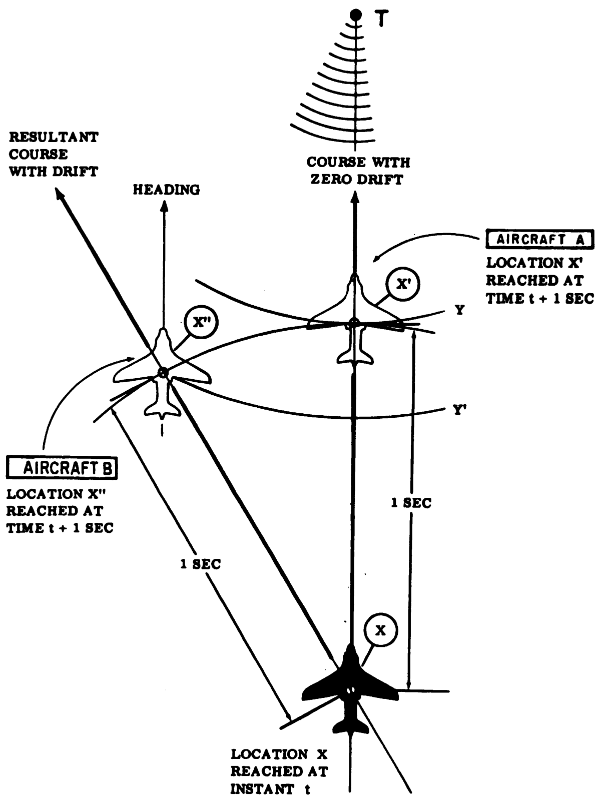
T
RESULTANT COURSE WITH DRIFT
HEADING
COURSE WITH ZERO DRIFT
AIRCRAFT A
LOCATION X' REACHED AT TIME t + 1 SEC
X''
X'
Y
Y'
AIRCRAFT B
LOCATION X'' REACHED AT TIME t + 1 SEC
1 SEC
1 SEC
X
LOCATION X REACHED AT INSTANT t

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Figure 12-20. —Effect of drift on Doppler frequency shift

In the interval of 1 second, aircraft A has approached closer toward the transmitter than aircraft B. The evidence can be seen when comparing the arcs scribed at Y and Y'. Because of the faster rate of approach to the transmitter, aircraft A receives more cycles of the transmitted frequency per unit of time than aircraft B. This results in an apparent increase in frequency received by aircraft A over that received by aircraft B. The difference in the Doppler effect on received frequency of zero drift and drift conditions suggests a means of determining drift angle.

DOPPLER EFFECT IN AN/APN-122(V)

The Doppler frequency shift previously described also occurs when the transmitter and receiver are in motion together, as when carried in an aircraft, and received signals are signals reflected from a fixed point on the earth's surface. The receiver will sense a

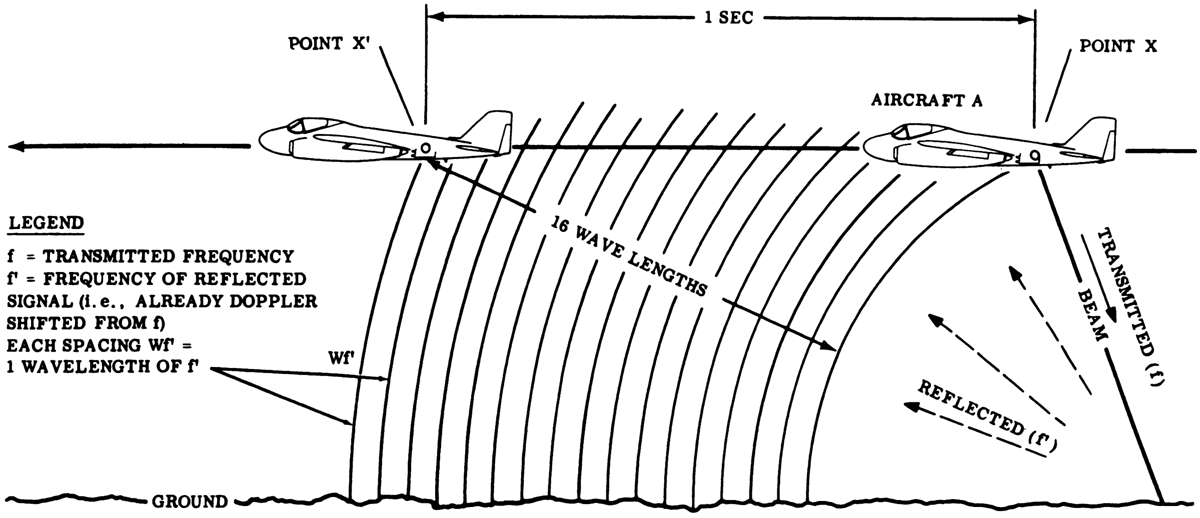
1 SEC
POINT X'
POINT X
AIRCRAFT A
LEGEND
f = TRANSMITTED FREQUENCY
f' = FREQUENCY OF REFLECTED SIGNAL (i.e., ALREADY DOPPLER SHIFTED FROM f)
EACH SPACING Wf' = 1 WAVELENGTH OF f'
Wf'
16 WAVE LENGTHS
TRANSMITTED (f)
BEAM
REFLECTED (f')
GROUND

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Figure 12-21.—Frequency shift: airborne transmitter-receiver with oblique beam.

Doppler frequency shift that is directly proportional to the speed of the aircraft. The ratio of frequency shift to groundspeed will be twice that illustrated in figure 12-19 and 12-20, since a proportional shift occurs in the signal on its way to the earth's surface and occurs again to an equal degree, during straight line flight, in the signal returning to the receiver. To obtain the largest possible frequency shift, it is necessary to focus the transmitted beam toward the earth at that angle which will yield the largest ratio of change in distance between the transmitter-receiver and the earth's surface. The desired rate of change is obtained when the transmitted beam is inclined toward, or away from, the direction of the aircraft's heading. Figure 12-21 illustrates the Doppler shift sensed by an airborne transmitter-receiver in which the beam is focused obliquely downward and aft of the aircraft's longitudinal axis.

In figure 12-21, aircraft A flies from point X to X' in 1 second. The signal f' cps is reflected from the ground toward the receiver. Each second the receiver recedes from the reflected signal a distance equal to 16 wavelengths of frequency f'. Because each wave must catch up with the receiver, the time between each of the reflected waves is increased and therefore delayed in arrival which, in effect, is as if the reflected signal frequency f' had decreased to f'-Hz.

To sense drift and heading velocities simultaneously, two transmitter beams are utilized

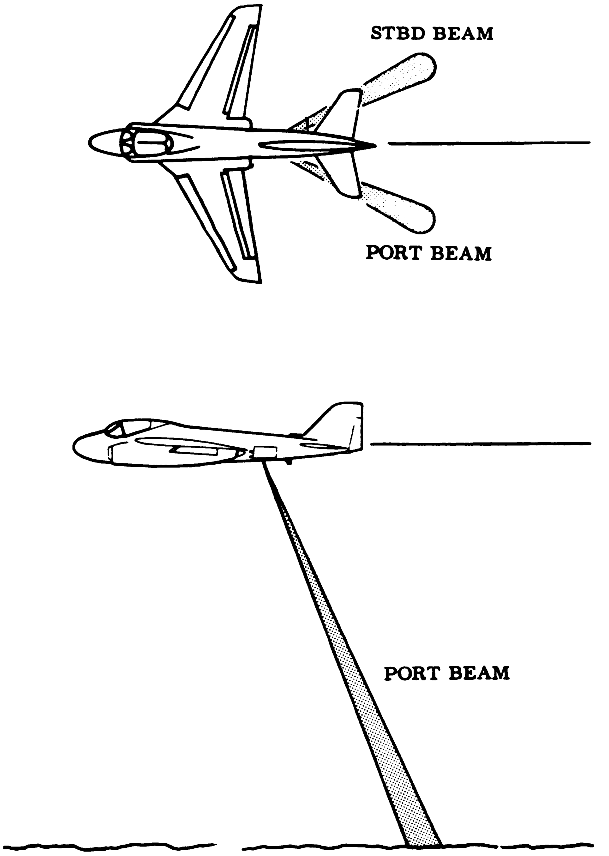

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Figure 12-22.—Beam orientation of Radar Navigation Set AN/APN-122(V).

which are directed laterally relative to aircraft heading as well as earthward and aft. In Radar Navigation Set AN/APN-122(V) the two beams are directed symmetrically, one to port and one to starboard of the aircraft's longitudinal axis. The orientation of the transmitter beams relative to the horizontal and vertical planes is illustrated on figure 12-22.

Effect of Drift on Frequency

The Doppler effect in an aft oriented dual beam system is illustrated in figure 12-23. Assuming the aircraft is not drifting, simultaneous radiations of each beam are reflected back to the aircraft from separate points on the earth's surface. The time in transit of the microwave energy in each beam is a direct function of the aircraft velocity. If they could be seen, the continuous waves of transmitted energy would form dual traces across the earth's surface, these traces comprising successive instantaneous points of reflection.

In figure 12-23 the port transmitted beam P has a rate of travel equal to its corresponding starboard transmitted beam S. Therefore, points RP and RS and RP' and RS' are the instantaneous points of reference for determining the rate of travel by the received beams of aircraft A and B, respectively. In the zero drift condition illustrated, aircraft A maintains heading H from X to X' for 1 second. The rate at which A recedes from reflecting points RP and RS is equal; therefore, the effective wavelength of the RF energy in beams P' and S' is equal. Since Doppler frequency shift is proportional to the relative velocity between the reflector (earth) and the receiver, the Doppler frequency shift in beams P' and S' of A is equal. In the drift to port condition illustrated, aircraft B encounters drift forces and covers ground track GT in 1 second. The rate at which B recedes from reflecting point RS' is greater than the rate at which it recedes from point RP'; therefore, the distance that beam S' of aircraft B travels in 1 second is greater than its associated beam P' in equal time by the distance from point Z to RS'. Since the rate of travel of effective wavelength for beam S' is greater than for beam P' in a port drift condition, the Doppler frequency shift is greater in S' than in P'. If the drift were to starboard instead of port, the largest Doppler frequency shift would occur in the port beam.

From the foregoing it can be seen that by using dual oblique beams, the direction of drift can be derived from the received beam which registers the least frequency shift. The velocity of drift can be computed from the difference between the magnitude of frequency shift in each beam, and ground speed can be computed from the sum of the magnitudes of frequency shift in each beam. The preceding is, in general, the method used for deriving direction and velocity of drift and groundspeed in radar navigation sets.

Functional Theory of the Radar Navigation Set

Two narrow beams of continuous microwave energy are transmitted by the transmitter-receiver and focused obliquely toward the earth. The beams are displaced laterally, one to port and one to starboard, and aft (fig. 12-21). A portion of the transmitted energy from each beam is reflected from the earth's surface at an angle sufficient to be intercepted by the receiving portion of the transmitter-receiver antenna. Each received CW signal is mixed with continuous samplings of the transmitted signal, within the waveguide assembly of the antenna, then coupled to their respective port or starboard crystal detectors. The resultant difference frequency output signal (f_{dp} and f_{ds}) of each detector are proportional to the aircraft's velocity along the port and starboard beam axes, respectively. These Doppler signals are of equal frequency as long as the aircraft maintains a straight line heading with no pitch or roll. If the aircraft drifts to port or starboard, its drift is sensed as a decrease in Doppler frequency derived from the beam that is focused in the direction of drift, and increase in Doppler frequency derived from the beam focused opposite to the direction of drift.

Due to the lobe pattern of the transmitted beams, the reflected energy of each beam comprises a narrow band of frequencies rather than a single frequency. The resultant narrow-band Doppler difference signals (port Doppler frequency and starboard Doppler frequency) are fed from the port and starboard crystal detectors, respectively, to the dual channel amplifier assembly where each is amplified under automatic gain control and then fed to the signal data converter.

Using what are initially only noise inputs, the signal data converter initiates a search

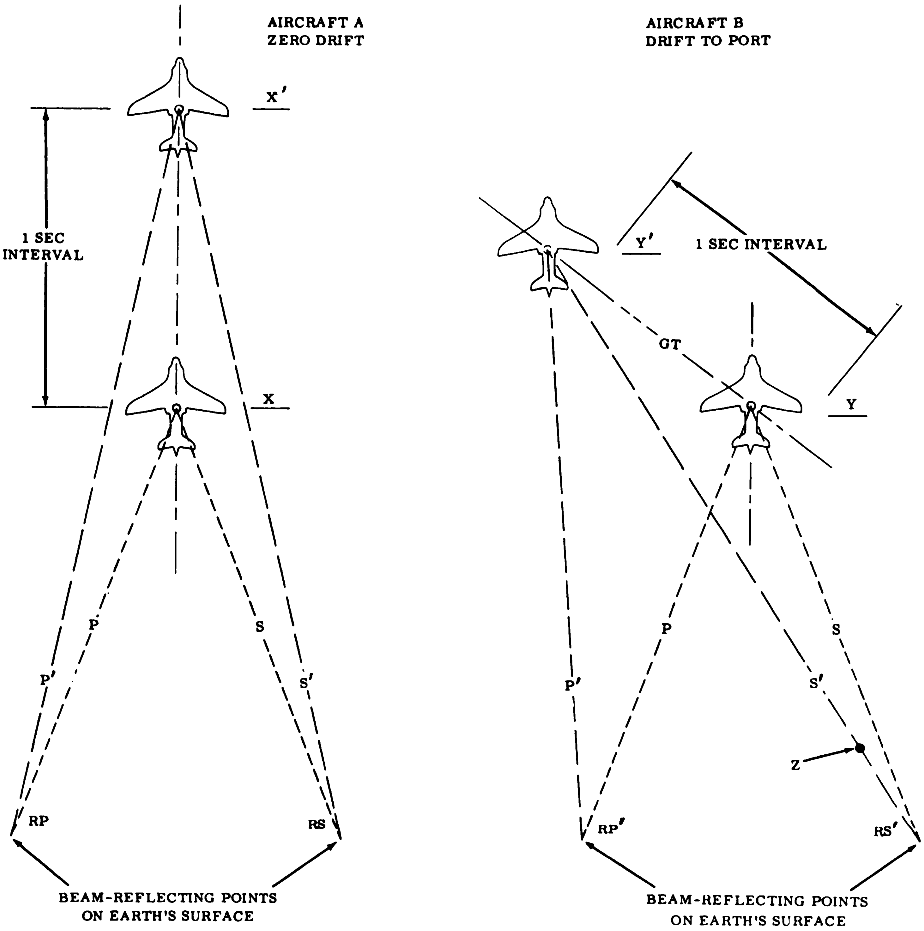

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Figure 12-23. –Effect of drift on frequency shift in dual beams.

function to acquire well-defined Doppler signals in both port and starboard channels. Simultaneously this converter supplies gain-increasing AGC feedback voltages to the amplifier assembly and a memory signal to be used in the ballistics computer. This memory signal is also used to cause an indicator lamp to come on, indicating that the signal data converter is operating in the search mode. When a satisfactory Doppler signal is acquired, the signal data converter will lock on and track the center of each Doppler energy spectrum and convert these signal frequencies to rate-proportional pulse outputs. The memory signal is cut off and the indicate or lamp goes out. These rate-proportional pulse outputs, which are representative of aircraft velocity data, are then routed to the balistics computer.

CHAPTER 13

INFRARED DETECTION

Infrared, or IR as it is sometimes called, is assuming increasing importance in missle guidance, target detection, fire control, communications, and mapping. Like radar, infrared was developed and used for military purposes during World War II. Unlike radar, however, the use of infrared has received little publicity. In some military applications, infrared energy has advantages over radar. Infrared, used as a medium of communications, is usually less susceptible to counterdetection and interference than is radar or visible light. Infrared equipment is generally less complex than radar equipment used for similar tasks.

ELECTROMAGNETIC SPECTRUM

IR is a form of electromagnetic energy, with certain characteristics identical to those of light and RF waves. Among these characteristics, some of the more important ones are reflection, refraction, absorption, and speed of transmission. Infrared waves differ from light, RF, and other electromagnetic waves only in wavelength and frequency of oscillation.

The frequency of IR ranges from approximately 300,000 megahertz to 400 million megahertz. Its place in the electromagnetic spectrum (fig. 13-1) is between visible light and the microwave region used for high definition radars. This part of the spectrum is usually discussed in terms of wavelength, and it is generally accepted that the IR spectrum lies between 0.72 and approximately 1,000 microns (1 micron equals 0.0001 centimeter).

The IR portion of the electromagnetic spectrum is frequently divided into the following three parts:

1. The near infrared (NIR) which extends from the visible region out to around 1.5 microns.
2. The intermediate infrared (IIR) which extends from 1.5 to 5.6 microns.
3. The far infrared (FIR) which extends from 5.6 microns to microwave frequencies.

Some confusion in terminology exists because infrared energy is so close to the visible range of wavelengths in the electromagnetic spectrum. Thus, it is not uncommon to hear references to "infrared light," although the term is inaccurate. Infrared waves are also loosely referred to as heat waves, because of the well-known fact that a solid object subjected to radiation by infrared energy undergoes an increase in temperature. Heat differs from infrared waves in much the same way that electricity differs from radio waves.

INFRARED RADIATION

All objects above absolute zero (0° K or -273° C or -460° F) emit infrared radiation. Radiation from any given object is emitted over a wide range of wavelengths, but it reaches a peak at one particular wavelength. This point is of considerable interest in military applications, as will be shown later. Detection of infrared energy depends on the contrast between IR from the source under consideration and the radiation emitted by the background. A cold object with a warm background has just as good target definition as a warm object with a cold background.

There are a number of advantages in using IR for target detection rather than some other form of electromagnetic transmission. Among these are the following:

1. IR systems are passive.
2. Althought IR systems can be confused, complete jamming is just about impossible.
3. Military targets are usually good sources of IR.
4. IR systems may be made smaller, lighter, less complex, and less expensive than other comparable systems.
5. IR systems have higher target resolution.

EMISSIVITY

One of the most useful concepts employed when working with IR is the "black body." A black body is defined as an object which absorbs all radiation incident on it. Conversely, the radiation emitted by a black body is the maximum possible for any given temperature. This black

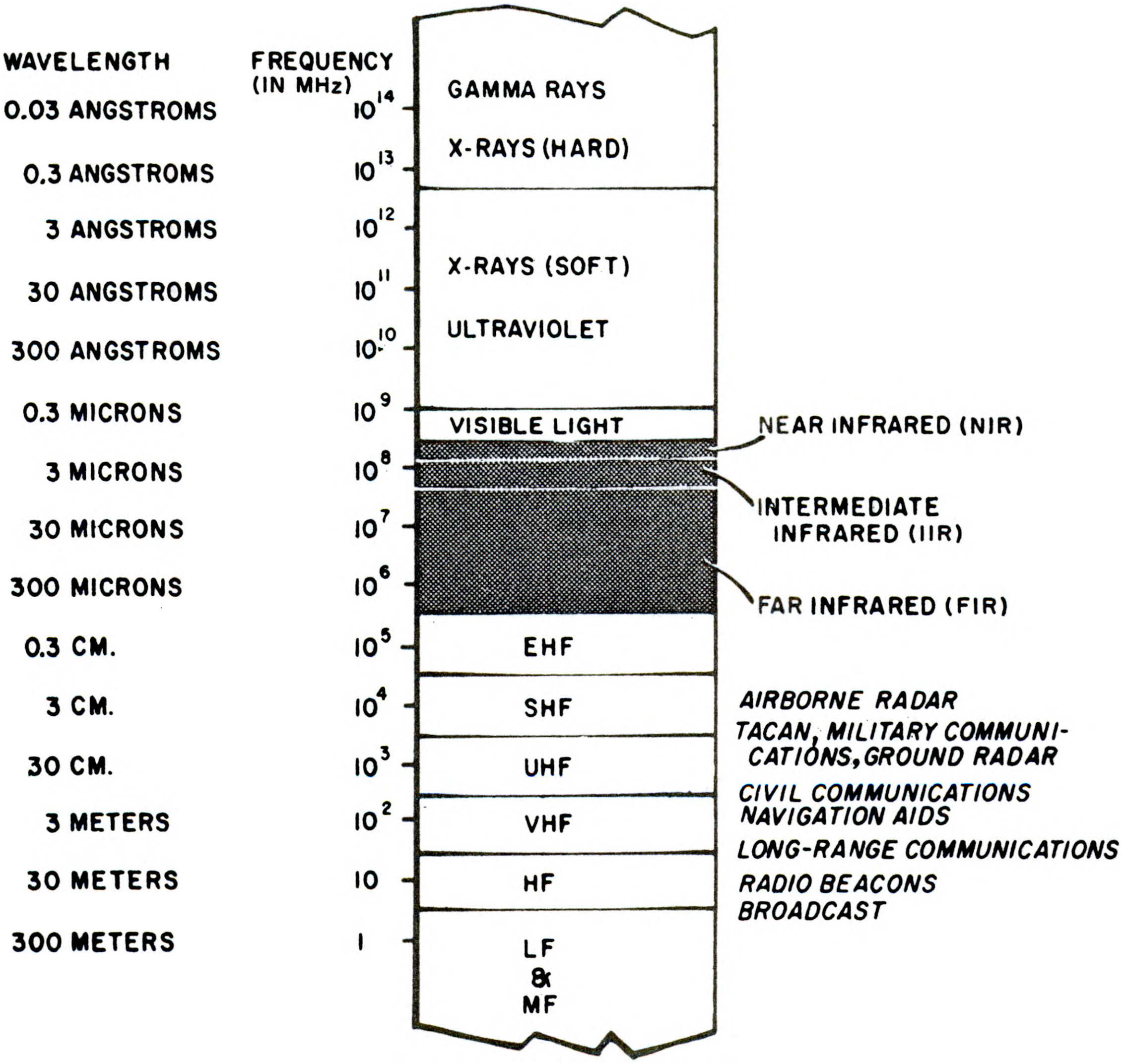

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Figure 13-1.—Electromagnetic spectrum, showing different wavelength units used in different bands of the spectrum.

body is then a perfect absorber and radiator of IR at all temperatures and for all wavelengths.

In order to compare the radiation emitted by an actual source with that of a perfect radiator, the concept of emissivity is employed. Emissivity is defined as the ratio of the total radiation emitted by any object at any temperature (T) to the total radiation which would be emitted by an ideal black body at the same temperature. The emissivity of any object depends on the amount of energy its surface can absorb. If the surface absorbs most of the IR striking it, then it will emit a relatively high amount of radiation, and the emissivity of the object will be comparatively large. By the same reasoning, if the surface reflects most of the incident radiation, the object will have a relatively small emissivity. By definition, a black body has an emissivity of unity. Therefore, any other object will have an emissivity of less than one. Table 13-1 shows the emissivity of various surfaces.

Table 13-1.–Emissivities of various surfaces

Surface	Emissivity
Black body	1.00
Lampblack	0.95
Painted	0.90
Steel, cold-rolled	0.60
Aluminum paint	0.25
Steel, stainless	0.09
Aluminum aircraft skin	0.08
Aluminum foil	0.04
Silvered mirror	0.02

Laws of Emissivity

The basic laws which describe the characteristics of IR were developed first for black body radiation, the ideal case, and then modified to describe the radiation from any source.

The most important parameter in determining the IR characteristics of any body is its temperature. As the temperature of an object changes, two specifics changes in the IR characteristics take place: The wavelength where peak radiation occurs is shifted, and the total energy radiated varies with the fourth power of the temperature. These fundamental relationships are given by two laws which are discussed in the following paragraphs.

WIEN'S DISPLACEMENT LAW.–This law states that the wavelength at which maximum radiation occurs, λm is inversely proportional to the absolute temperature of the body. This can be expressed by

$$\lambda m = \frac{K}{T}$$

where the wavelength is given in microns, and the constant (K) has a value (for a black body) of about 2,900. For example, a block of ice emits its peak energy at about 10 microns, while energy emitted from a jet aircraft engine peaks at about 3.5 microns. The relationship is shown in figure 13-2.

STEFAN-BOLTZMANN LAW.–This law states that the radiation intensity, E, is directly proportional to the fourth power of the absolute temperature, expressed as

$$E = \sigma T^4$$

where E has dimensions of power per unit area and σ is the proportionality constant. In other words, if the temperature of an object is doubled, the radiation emitted from the object will be 16 times as much.

The Stefan-Boltzmann Law can be modified to include the emissivity factor; and by using the right units, the total radiation can be obtained by

$$E = \varepsilon\sigma T^4$$

where ε is the emissivity factor of the radiating surface.

A black body at an absolute temperature of 300° (81° F) will radiate 46 milliwatts of power per square centimeter of its surface. A painted surface, such as the skin of a commercial airliner, at the same absolute temperature will radiate 41 milliwatts per square centimeter. If this aluminum aircraft skin were not painted, the emissivity factor would be considerably smaller, and the radiation would be less than 4 milliwatts of power per square centimeter.

As mentioned previously, IR from a source will be distributed over a good part of the spectrum, but the maximum radiation occurs at some specific wavelength. Figure 13-3 shows the distribution of energy radiated from a black body at various temperatures.

As an example, IR from jet and rocket engine exhaust plumes is primarily due to the molecular excitation of water vapor and carbon dioxide which are characteristic byproducts of combustion. This molecular radiation peaks at 2.7 microns (due to water vapor and carbon dioxide) and 4.3 microns (due to carbon dioxide alone). In a practical situation, however, more usable radiation is obtained from the hot tailpipe and other heated surfaces.

TRANSMISSION CHARACTERISTICS

In military applications of IR systems, the transmitting medium is generally the atmosphere. The effect of the atmosphere on the transmission of IR is a very important factor in considering the overall effectiveness of the system.

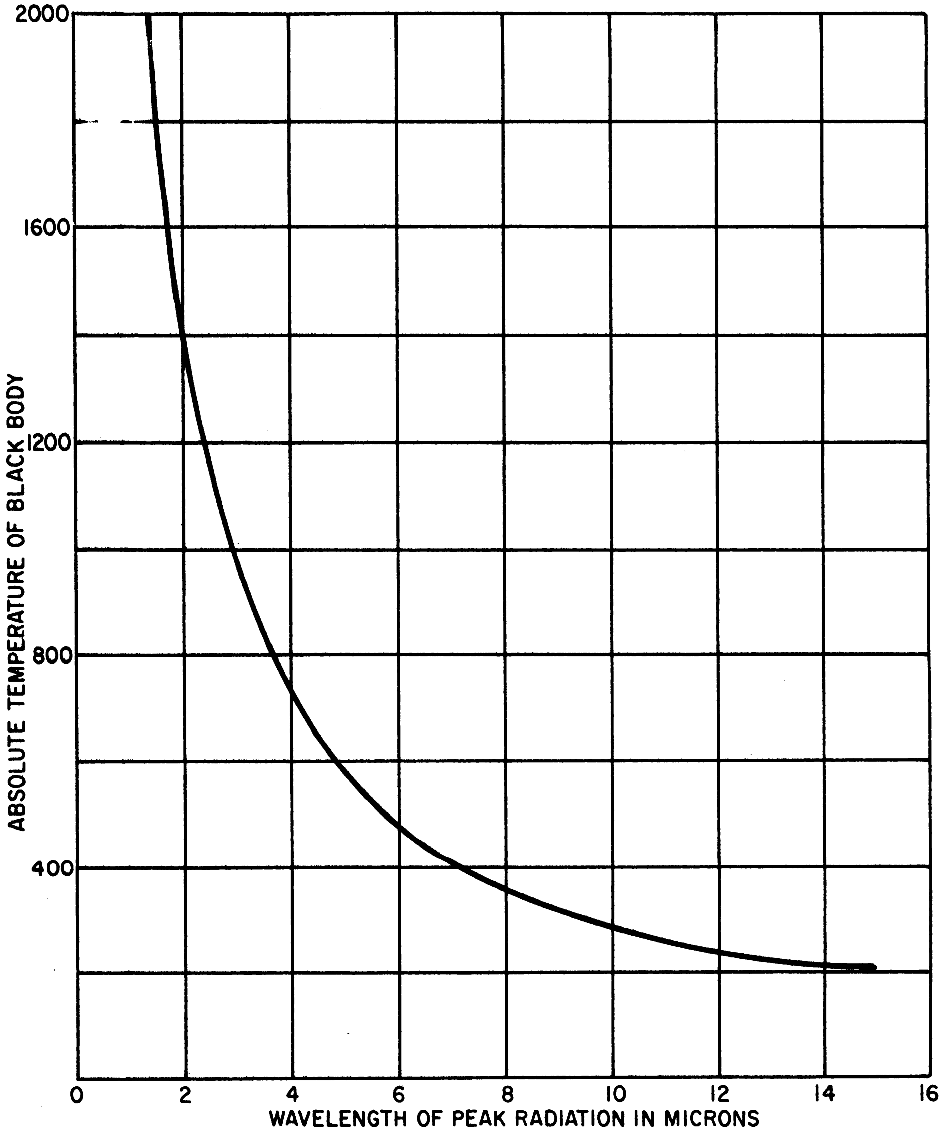

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Figure 13-2. –The wavelength of the peak radiation from a black body in relation to its temperature.

Atmospheric Absorption

There are two primary causes of atmospheric attenuation: scattering by suspended solids, and absorption by free molecules. These two influences on the attenuation are additive, but the absorption is the most important factor.

The amount of scattering caused by particles depends on the relationship between the wavelength of the radiated energy and the size of the particles. If the wavelength involved is considerably shorter than the dimensions of the particles, then the scattering is just about independent of wavelength. Since this is generally the case in the IR spectrum, the attenuation due to scattering can be measured at one wavelength and then applied over a relatively wide band of wavelengths.

This technique does not work, however, with attenuation due to molecular absorption. The amount of absorption is closely connected with the wavelength. The two substances in the

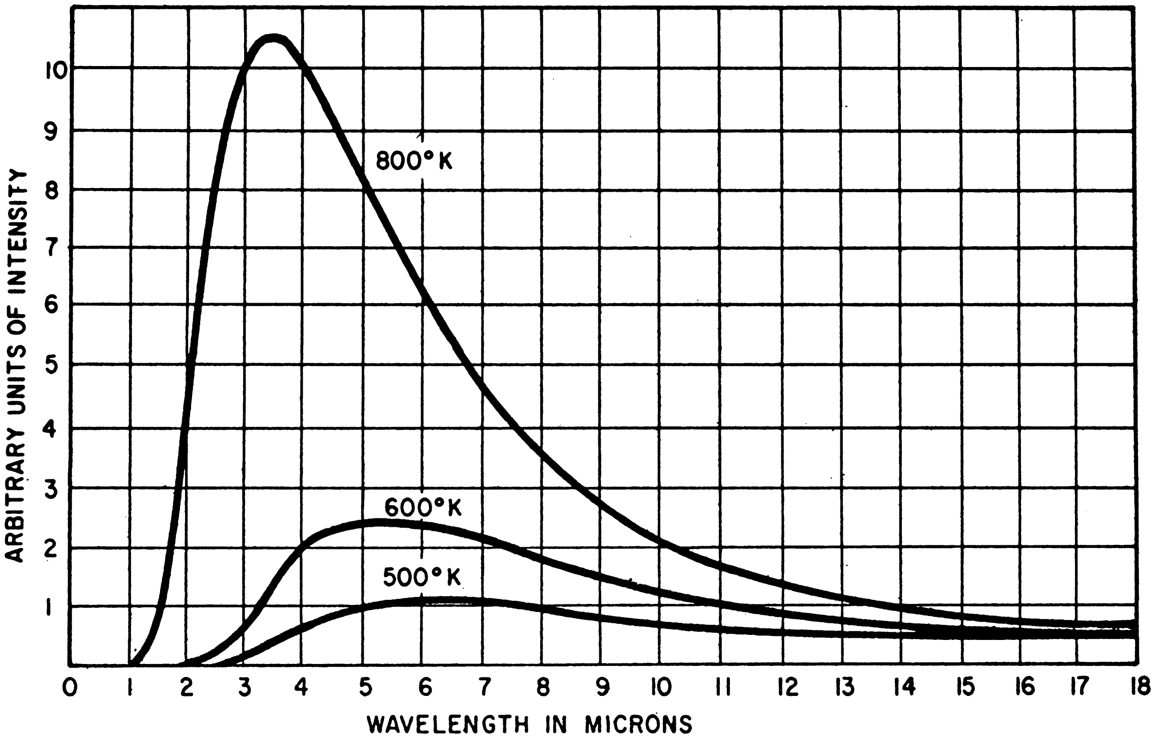

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Figure 13-3.–IR distribution curves for a black body at various temperatures.

atmosphere which absorb the most radiation are water vapor and carbon dioxide. In both of these substances, there are several wavelength bands where the absorption is relatively large. This condition is caused by molecular resonance. (Each molecule has a "natural frequency" of vibration, or resonant frequency.)

The resonant frequencies of these molecules are in the infrared region, and their structure is such that this natural vibration creates an oscillation of electric charge in the molecules which increases the absorption. At low altitudes, where the atmosphere is more dense, this absorption is so great that in some wavelength bands the percentage of radiation transmitted drops rapidly to zero. Between these absorption bands are areas where the atmospheric attenuation is not so great. These transmission bands are called "windows." The transmission windows in the atmosphere are approximately as shown in table 13-2.

Table 13-2.–Wavelength limits of IR transmission windows in the atmosphere.

0.95	-	1.05	microns
1.2	-	1.3	microns
1.5	-	1.8	microns
2.1	-	2.4	microns
3.0	-	5.0	microns
8.0	-	12.0	microns

Figure 13-4 shows the transmission characteristics of the atmosphere at two different altitudes. It will be noted by reference to figure 13-4 that the 2.7 and 4.3 micron radiation readings from a jet exhaust plume occur at frequencies of high absorption. The radiation resulting from hot tailpipe surfaces is a function of tailpipe material and temperature, usually peaking at about 3.5 microns. This frequency is in

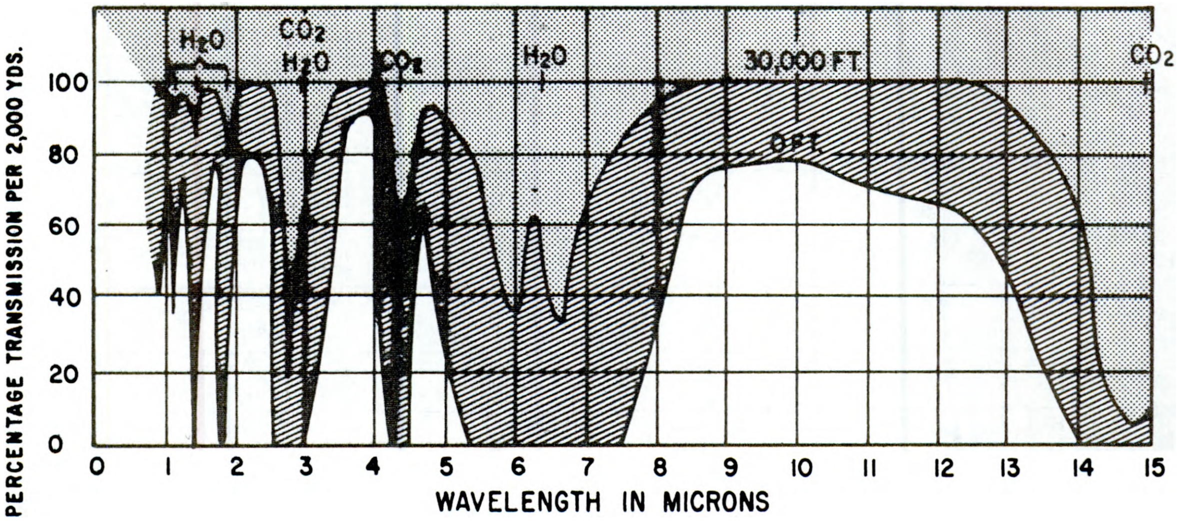

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Figure 13-4. –Atmospheric transmission characteristics.

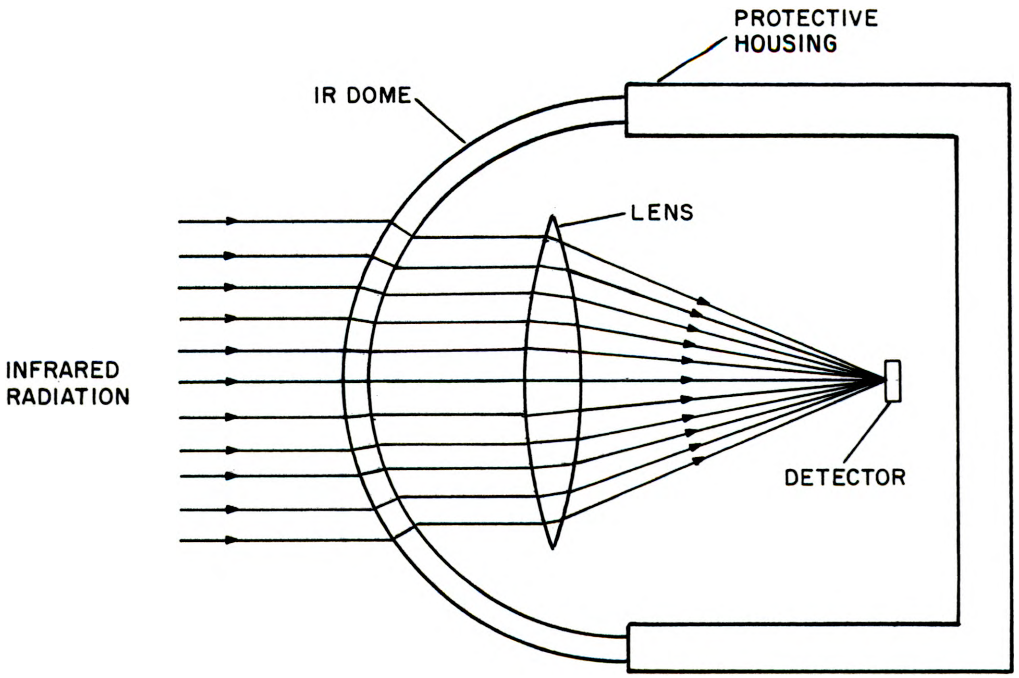

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Figure 13-5. –Simple IR optical arrangement.

the region of an atmospheric window or low absorption band. It will also be noted that the absorption bands are much narrower at high altitudes due to the thinner atmosphere. These absorption bands will, therefore, be of lesser consideration in the design of high altitude systems.

OPTICAL DEVICES

Because of the similarity between infrared and visible light, optical devices are usually employed to gather and focus the infrared radiation upon the detector. A simplified infrared optical arrangement is shown in figure 13-5. This illustration shows a simple optical system which could be used to focus IR radiation. The entire system is enclosed within a protective housing to protect the detector and optical system from the weather. The dome is a continuation of the protective housing and must be able to pass infrared radiation easily.

Typical materials from which domes are fabricated include glass, quartz, synthetic sapphires, germanium, and silicon. The transmission coefficient of the optical material is an important factor in the design of infrared equipment. For NIR, and generally for IIR, glass and quartz are satisfactory. Figure 13-6 shows that glass, quartz, and synthetic sapphires have excellent transmission characteristics in the visible and near infrared regions. They cut off sharply in the middle infrared region. Optical glass is completely opaque to wavelengths longer than 3 microns, quartz cuts off at 4 microns, and synthetic sapphire loses its transparency at wavelengths greater than 6 microns.

Germanium and silicon are semiconductor materials which are opaque to visible light and transparent throughout most of the near and middle infrared regions.

A wholly different type of optics is required for FIR. Single crystals of silver chloride, rolled flat, are satisfactory windows for the transmission of FIR. Sodium chloride (rock salt), grown in single crystals and cut and ground into a lens or window, is excellent. However, rock salt is highly soluble in water and must be protected from the atmospheric moisture. Therefore, rock salt is not practical to use as an IR dome material.

There are a number of problems involved in the design of IR optical systems. The material used must match the wavelength to which the detector will respond. Optical materials

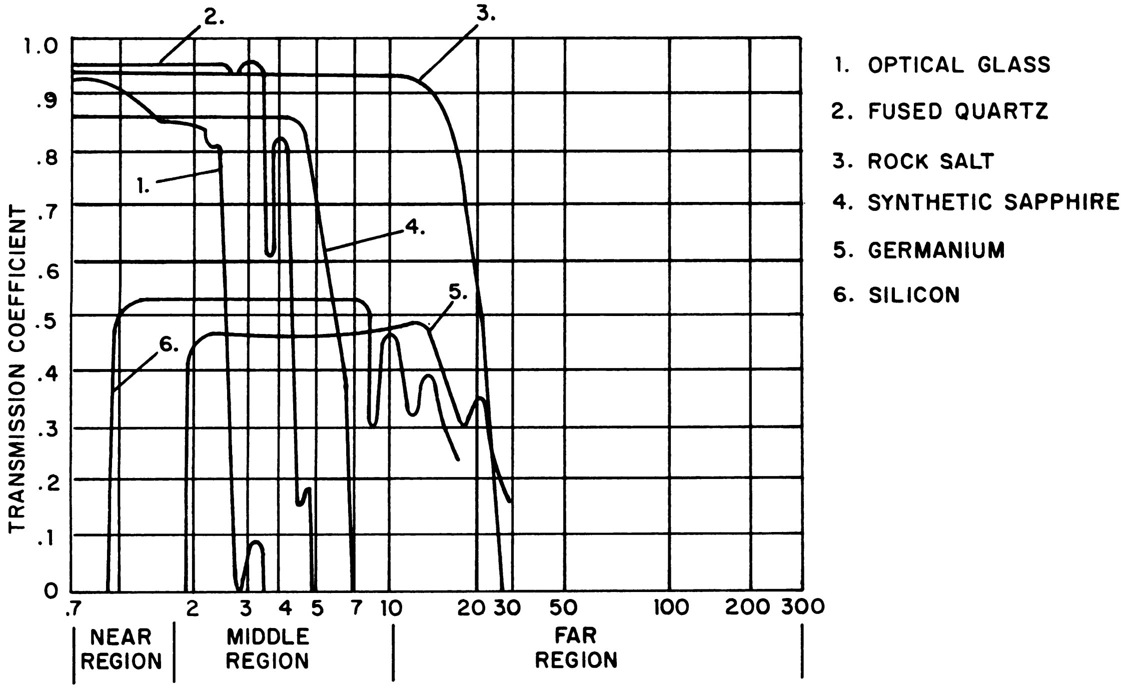

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Figure 13-6.–Wavelength vs. transmission coefficient.

are generally weak physically, and many have a low resistance to high temperature and thermal shock. Chemical reactions and pressure will change the properties of some materials.

Another vital problem is that of system heating. If any part of the system becomes heated by energy it has absorbed, this energy will be reradiated at wavelengths that differ from those of the original radiation. If the detector is sensitive to these new wavelengths, this source which is much closer than the target will obscure the target or cause "ghost" images.

Attenuation in optical materials is primarily due to two things: surface reflections, usually overcome by antireflection coatings; and attenuation by the material. The latter is the more serious problem.

IR systems often have a chopping reticle in the principal focal plane. The chopper is generally a rotating disk with some clear and some opaque areas. Although a chopper is not absolutely necessary in a search system, it has several useful properties. The chopping rate furnishes a conveniently high carrier frequency for the electronic amplifiers. The reticle pattern can operate as a discriminator or filter. For example, it can be designed for the type of backgrounds expected in order to provide better differentiation of target and background.

Optical filters are used in IR instruments to isolate certain wavelength regions of interest, such as atmospheric windows, and to screen out undesired wavelengths. Three general types of filters are as follows:

1. Those which pass short waves.
2. Those which pass a particular band of waves.
3. Those which pass long waves.

DETECTORS

The most critical component of any IR system is the detector. The characteristics of the atmosphere and the source, if it is a military target, cannot be changed. Optical materials are somewhat standardized, as are display devices and control circuits. Although research and development in the last decade has resulted in some very good all-round detectors, it is still necessary to use care in choosing the proper one for a particular application.

Many variables must be considered in the choice of a detector. The characteristics of the radiation involved will determine which type of detector will best fit the needs of the system.

DETECTOR CHARACTERISTICS

In order to compare the relative merits of different detectors in different situations, it is necessary to introduce several parameters of detector operation. These parameters make it possible to discuss the characteristics of a particular detector in terms which can be applied to any detector.

Responsivity

When IR strikes a detector material, either photoelectric or thermal, a change takes place which produces an electrical output signal, indicating that the material has been exposed to IR. The amount of signal produced by each unit of input radiation intensity is called the responsivity (R) of the detector, and is expressed as

$$R = \frac{\text{output}}{\text{input}}$$

generally in volts per watt. Many factors influence the responsivity, such as temperature of the detector and source, detector area, spectral distribution of the radiation, detector time constant, etc.

Spectral Response

One important influence on the responsivity of a detector is the change in detector sensitivity with changes in the wavelength of received radiation. The spectral limit of responsivity is considered to be the wavelength where the responsivity is half that of its maximum value. Since the spectral response is a non-linear characteristic, it must be known for each wavelength considered, and any discussion of values must include the details of the conditions involved.

Time Constant

In any IR scanning system, the time constant of the detector must be such that the detector can fully respond before the radiation intensity changes. The time constant is considered to be the time required for the detector to develop 63 percent of its maximum output signal. The maximum scanning rate is dependent upon this time constant.

Noise

Noise exists in any circuit that carries current. Most outside noises can be eliminated or drastically reduced by shielding and proper design, but thermal noise is an ever-present problem.

Power supplies employed with IR detectors must be extremely well filtered. Since the IR radiation received by the detector is very small, noise of any appreciable amount could be sufficient to make weak IR signals or cause false targets. Transistors, for an example, are useless in IR amplifiers because of their inherent noise characteristics.

Many different types of noise are generated within IR systems. Among these, the most important are as follows:

1. Current noise, caused by bias currents within the detector.
2. Johnson (thermal) noise, caused by thermal fluctuations in the detector material.

At low bias voltages, current noise is negligible and the output noise voltage consists almost entirely of Johnson noise. The current noise increases linearly with bias voltages and may eventually become the primary source of noise.

NOISE EQUIVALENT POWER.–Another useful and important detector parameter is the noise equivalent power (NEP) of a detector. NEP is the radiation power in watts which must strike a detector to produce a signal response from the detector equal to the noise output (in other words, signal to noise ratio of 1) over a reference bandwidth.

When comparing two different IR detectors, the one with the lower NEP has the higher useful sensitivity. Since this tends to be confusing, another parameter is used–the detectivity. This figure is simply the reciprocal of the given NEP of a detector, so that the higher detectivity a cell has, the higher is its useful output. For example, a detector with an NEP of 4.0×10^{-9} will have a detectivity of 2.5×10^{8}.

The best IR detector would be one having the greatest possible responsivity, the widest possible spectral response within the frequency band of interest, and the lowest possible NEP (or highest possible detectivity). A properly chosen detector, with the necessary operating conditions, might have a maximum range of 90 miles with a signal to noise ratio of 5 from a 1 square meter target at 300° Kelvin. This range is equivalent to an ability to detect IR emitted by a cubic inch of ice at 3 miles.

Photodetectors

The three major types of photodetectors are photoconductive, photovoltaic, and photoemissive. Signal to noise ratio of the detector is the limiting factor in determining its effectiveness. These are used in the near infrared spectrum.

Photoconductors use a semiconductor crystal that absorbs the photon energy from the radiation which strikes the surface of the crystal, changing its resistance or conductivity. Quite a number of materials have been used for this type of photodetector, including lead sulfide, lead telluride, lead selenide, cadmium sulfide, and many others. Gold-doped germanium has been established as a good detector material, but some difficulties, such as the long time constant, must be considered.

Photovoltaic cells are similar to solar cells. These are semiconductors with a high resistance photosensitive barrier between the two layers. When exposed to IR, this cell builds up a potential difference between the two layers.

Photoemissive cells operate on the principle that electronic emission is caused by exposing the cathode to IR. In this type of emission, the number of electrons emitted depends on the intensity of the IR striking the cathode.

THERMAL DETECTORS

Thermal detection is accomplished by sensing the change in temperature of the detector material as a result of IR striking its surface. There are three different types of sensing elements employed in modern detectors to sense this temperature change. These are as follows:

1. The thermopile, which is a series combination of several thermocouples.
2. Bolometers, which sense the change in resistance of the detector material.
3. Pneumatic cells, which use the expansion of a gas as an indicator.

Thermocouple

One of the basic heat detectors is the thermocouple. When two dissimilar metals such as iron and copper are joined together and heat is applied to the junction, a measurable voltage

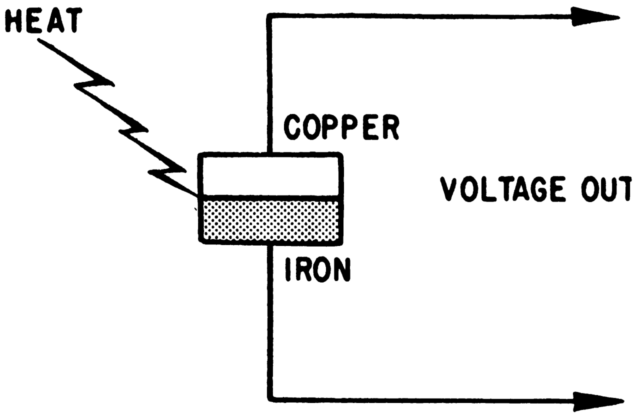

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Figure 13-7. –Thermocouple.

will be generated between them. Figure 13-7 shows a basic thermocouple.

The voltage difference between two metals is quite small, but the sensitivity can be increased to a point at which the thermocouple becomes useful as a detector of IR. The increase in sensitivity is obtained by connecting or stacking a number of thermocouples in series, so that they form what is known as a thermopile. The complete thermopile action is similar to that obtained when a number of flashlight cells are connected in series; that is, the output of each individual thermocouple is added to the ouput of the others. Thus, ten thermocouples, with individual output voltages of 0.001 volt, would have a total output of 0.010 volt when connected in series.

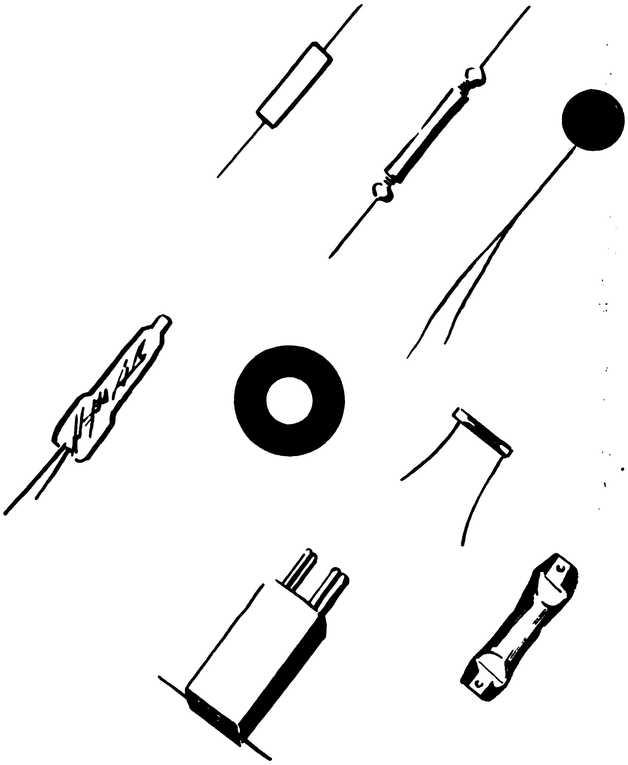
The effective sensitivity of a thermopile can be further increased by mounting it at the focal point of a parabolic reflector. When this method is used, IR given off by the target is focused on the thermopile by the reflector.

Bolometers

A bolometer is a very sensitive material whose resistance will vary, depending on the amount of IR to which it is exposed. There are two main classes of bolometers–barretters and thermistors.

A barretter consists of a short length of very fine wire (usually platinum) which has a positive temperature coefficient of resistance. (A substance has a positive temperature coefficient if its resistance increases with temperature, and a negative coefficient if its resistance decreases with an increase in its temperature.)

The thermistor is a type of variable resistor made of semiconducting material, such as oxides of manganese, nickel, cobalt, selenium, and copper. The thermistor has a negative temperature coefficient of resistance. Thermistors are made in the form of beads, disks, rods, and flakes, some of which are shown in figure 13-8.



AQ. 255
Figure 13-8. –Various thermistors

The heat sensitive materials of thermistors are mixed in various proportions to provide the specific characteristics of resistance versus temperature necessary for target detection.

Figure 13-9 shows the change in resistance which can be produced in a typical thermistor material and in a barretter. This comparison shows that the thermistor has the steeper temperature coefficient of resistance curve, and therefore is the more sensitive of the two sensors.

One simple type of infrared detector consists of two thin stripes of platinum which are used to form two arms of a Wheatstone bridge. To increase the thermal sensitivity of the strips, each is blackened on one side. The IR to be measured is applied to one of the strips,

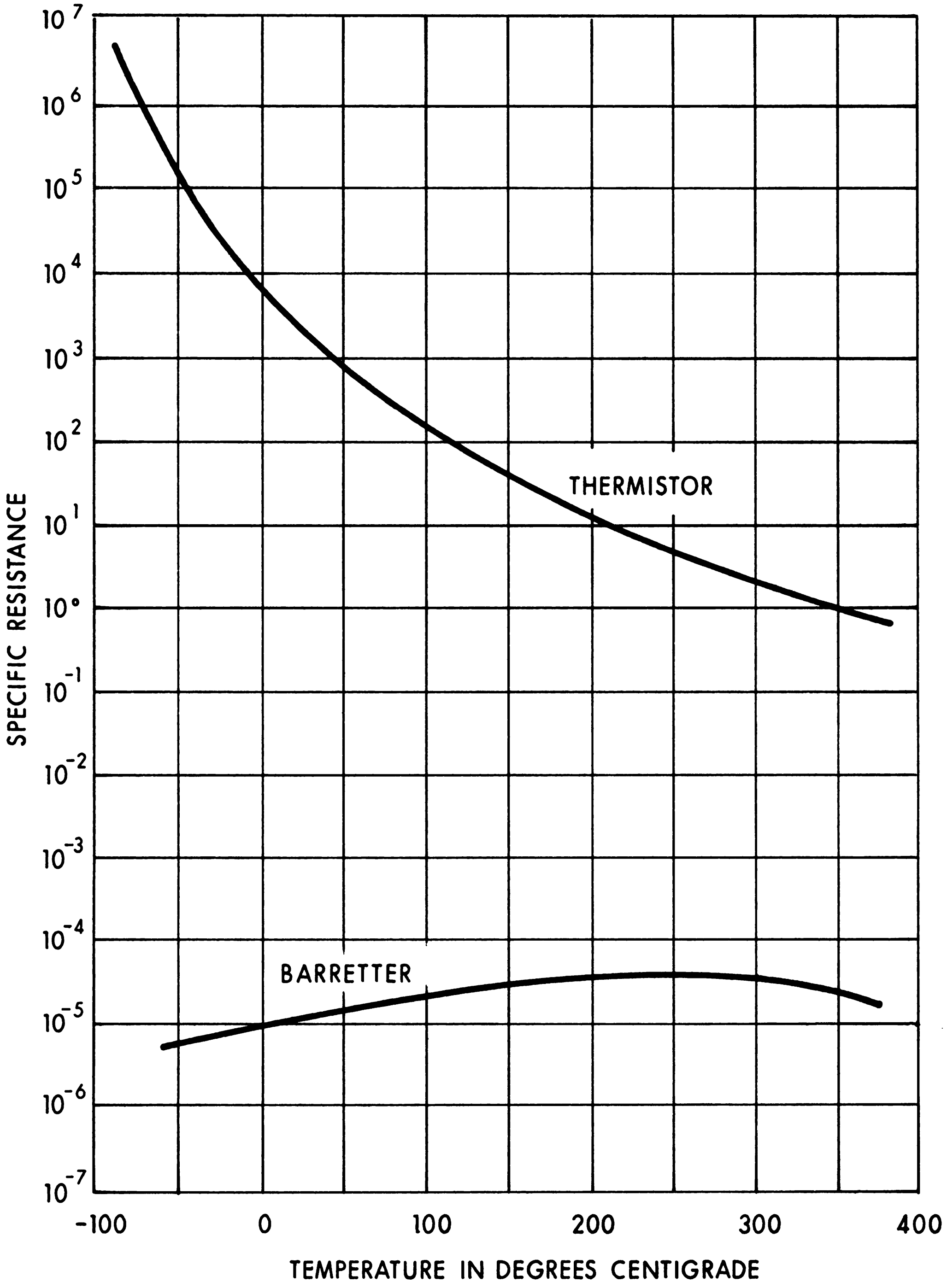


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Figure 13-9. –Comparison of thermistor and barretter sensitivity.

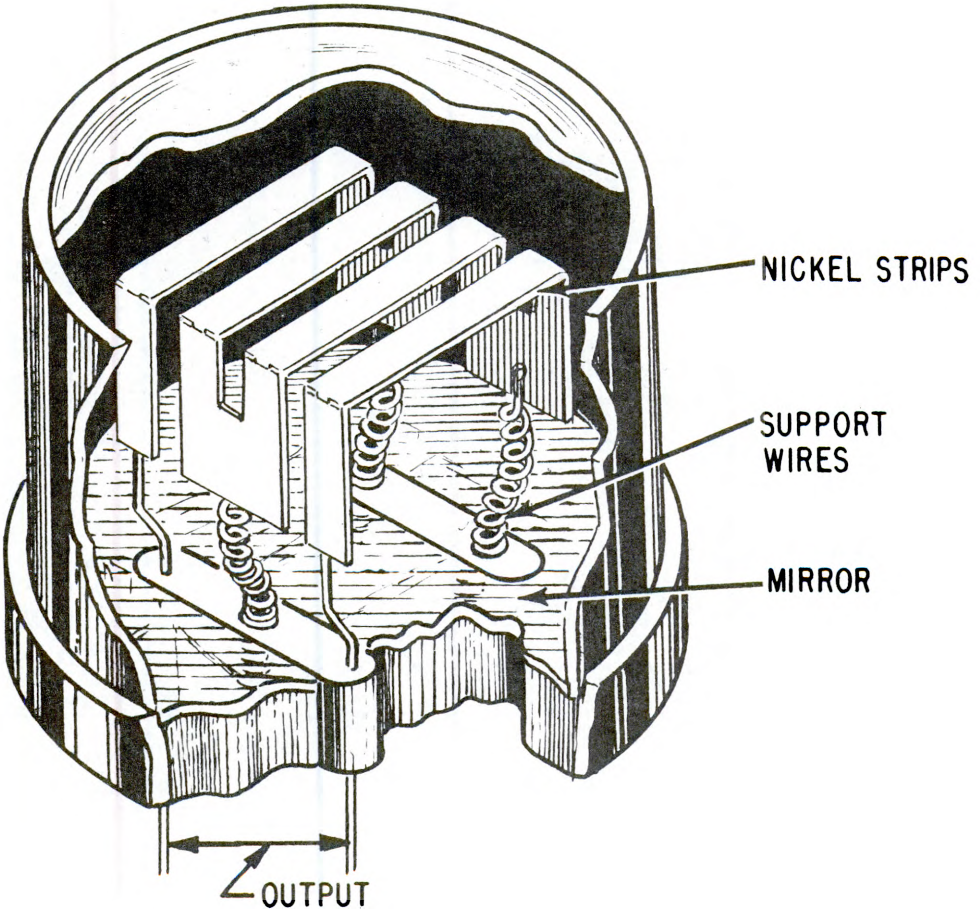

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Figure 13-10. –Infrared detecting device.

and is absorbed by its balckened surface. As the strip absorbs heat, its resistance changes and unbalances the bridge. The imbalance causes a change in current produced by an external voltage applied to the input terminals of the bridge.

A device of this kind is shown in figure 13-10. It consists of four nickel strips supported by mounting bars, which have electrical leads attached to them. A silvered parabolic reflector (mirror) is used to focus the IR on the nickel strips. The change of resistance in the strips produces unbalanced conditions in the bridge circuit which can be used to produce correction signals.

Pneumatic Cell

Another unique infrared detector is the pneumatic cell or GOLAY detector shown in figure 13-11. This detector is actually a miniature heat engine.

Infrared energy entering the window causes expansion of a volume of gas located between the reflecting diaphragm and the window. The lamp at the after end of the detector emits a light beam which is focused by the lens and then passes through the grid and onto the reflecting diaphragm. The expansion and contraction of the gases between the window and diaphragm will cause the diaphragm to change its shape in response to changes in the amount of infrared energy entering the window.

Changes in shape of the diaphragm will cause its light-reflective properties to vary accordingly, modulating its light output. The light reflected from the diaphragm will then pass back through the grid which is designed to intensify the variations of the reflected light. After passing through the grid, some of the

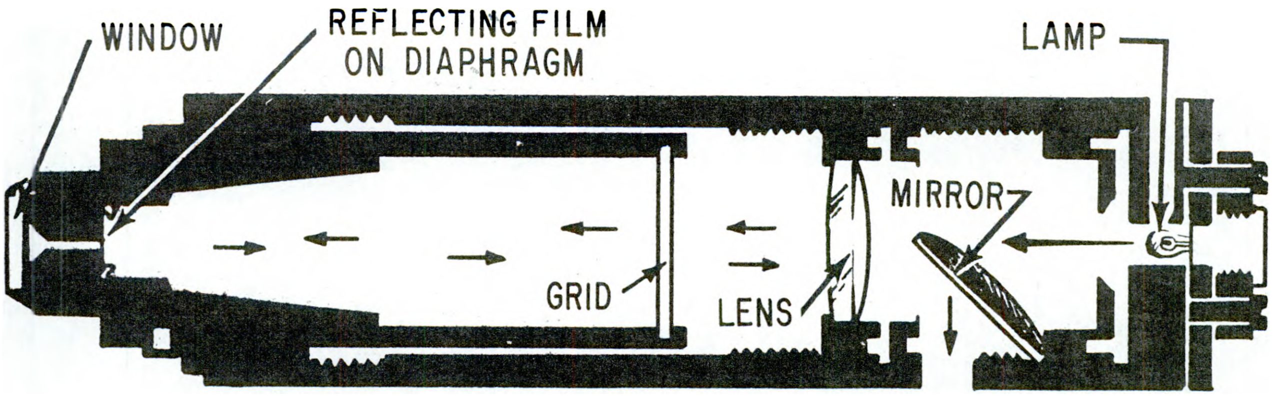

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Figure 13-11. –Golay detector.

light strikes the mirror and is reflected to a photocell of high sensitivity (not shown in the figure). The modulated output of the photocell is a voltage proportional to the intensity of the IR entering the window.

The Golay detector has the most rapid response of any infrared detector, but it can operate only when radiant heat is received intermittently. An optical chopper may be used to interrupt the flow of IR to the cell periodically. Another advantage of the Golay detector is its extremely wide bandwidth, making it a good choice for use in IR spectrum analysis.

APPLICATIONS

Military and industrial applications of IR have grown in number considerably in the last decade. A complete discussion of all applications would be beyond the scope of this manual. However, some of the systems and concepts applicable to military situations are discussed in the following paragraphs.

MILITARY USES OF INFRARED

Infrared devices found their first military uses during World War II as a snooperscope which operated in total darkness and outlined enemy troops by the heat radiated from their bodies. A rifle with a device known as the sniperscope made it possible to see a target in total darkness and fire with normal accuracy without the enemy becoming aware of one's presence.

Since infrared is invisible but behaves much like visible light (that is, it can be reflected and controlled in a beam pattern), it has served as a means of communication for specific wartime purposes. Development of equipment which would receive the invisible light was the foundation for the design and successful use of some highly important weapons. Infrared, when used for shortrange communication between sea-level stations, such as ships, affords excellent security. Infrared rays are limited to line of sight, and are rapidly attenuated at sea level; thus, IR acts in favor of security for shortrange communications. Military use of infrared for communications therefore requires a powerful source that can be modulated and sensitive receivers for detecting the modulated source. Such sources and receivers have been developed for near infrared energy.

Infrared is used in photography as it is effective against camouflaged targets. Night photography using infrared can produce a better visual presentation of terrain than the best mapping radar.

Infrared has invaded the navigation field. Groundspeed indicators are being developed that will compete with Doppler Radar. Anticollision circuits are under experimentation.

IR is also used in image forming devices, thermal or ship detection, and infrared radar. The portable infrared detector (PID) is a passive far infrared (FIR) equipment used for the detection of personnel, vehicles, tanks, small boats, and ships. It detects the difference in temperature between a body and its immediate background and provides and audible signal output. A larger far infrared system for ship detection is the stabilized ship detector (SSD).

This provides a permanent record of the true bearing of all targets that are detected within the angle scanned. Infrared radar uses a pulsed IR source and receives reflected IR energy as in microwave radar.

Infrared has excellent application to guided missiles. Military targets, such as ships, factories, and aircraft, are normally warmer than their surroundings. The presence of these targets may be detected by the heat radiation they emit. The radiation of heat at lower temperatures is particularly important in the passive detection of surface targets, since there is no economical way by which the enemy can camouflage his self-radiated heat.

The Felix bomb was the first guided missile to utilize IR. It was automatically guided by an infrared homing device in the nose of the bomb. The Felix bomb was thoroughly tested and declared reliable and adequate for operational use, but World War II ended before it could be used under combat conditions. This opened the way to a new and different method of guidance, infrared homing.

Homing guidance systems control the path of the missile by a device in the missile that reacts to some distinguishing feature of the target. They are the most accurate of all guidance systems. Homing systems are divided into the following three types, depending upon the source of target radiations:

1. Active homing—both the source which illuminates the target and the receiver which detects the echoes are carried in the missile.
2. Semiactive homing—the target is illuminated by some source outside the missile and the missile receiver utilized the target reflecons.
3. Passive homing-the missile receiver detects the natural radiation of the target.

Active and semiactive types generally use radar, whereas passive types use heat or light, or in some cases, home on a radio or radar transmitter.

The Sidewinder is probably the simplest and cheapest of all guided missiles. It uses an infrared homing system and is designed to destroy high-performance aircraft from sea level to about 50,000 feet.

The experimental Midas satellite, which was launched by the United States, employs infrared principles. It is equipped with an infrared scanning device capable of instantaneous spotting and reporting of the launching of a hostile ballistic missile. It is expected to provide complete and constant scanning of the earth's surface. Flashing an alarm of the blast-off of enemy missiles, would give the United States 30 minutes to prepare for nuclear bombardment.

While it is unlikely that radar will ever be entirely replaced by IR, it is already an established fact that IR possesses certain advantages over radar. It is expected that radar and IR will work as a team in many applications, such as fire control, guidance, and even search.

CHAPTER 14

TYPICAL AIRBORNE MISSILE CONTROL SYSTEM

The purpose of this chapter is to provide information on a typical airborne missile control system which the technician may be required to maintain. The Aviation Fire Control Technician is primarily concerned with missile guidance and control equipment installed in the aircraft. The missile itself contains guidance and control equipment which is not necessarily a matter of concern for the AQ; however, it is essential that he have a basic understanding of the fundamentals of missile guidance and control relative to the missile itself.

A general description of a typical airborne missile control system includes the purpose of the system, aircraft equipment, and the fundamentals of missile guidance and control.

The primary purpose of the airborne missile control system (AMCS) is to assist the pilot in carrying out attacks against enemy aircraft with a high probability of success under all environmental conditions. The intercept problem posed by this type of mission requires that the system enable the pilot to navigate to the target area, find and identify the target, acquire the target, and track it throughout the attack. The system must present steering information to the pilot by means of a radar indicator.

When the target is within firing range, the system must indicate this to the pilot, and furnish anticollision warning for recovery from the attack course. Normally this anticollision warning is in the form of a visual breakaway "X" on the indicator, although it may be an audible tone applied to the pilot's headset. Some systems also provide the pilot with a course to take (indicator presentation) upon breakaway to prevent flying through any of the target's debris. The system must function equally well for either firing guns or launching aircraft rockets.

The discussions in the course thus far have been limited to radar components. Chapters 5, 7, 8, 9, and 11 discussed the individual radar components. In this chapter they are presented as a complete system.

Missile guidance or missile control systems installed in naval aircraft are the outgrowth of intercept systems. Missile guidance systems are basically intercept systems with missile guidance capabilities. Systems designed primarily for the guidance and control of missiles are referred to as airborne missile control systems.

Usually the air intercept (AI) radar set makes up the greater portion of the system with the remainder being made up of the CW radar group, flight data unit, vertical gyro, two-plane rate gyros, and range adapter and/or converters. These components and their associated equipment are discussed in greater detail in Aviation Fire Control Technician 3 & 2, NavPers 10387, and it will behoove the reader to review the pertinent sections that he is not thoroughly familiar with at this time. A thorough understanding of these components combined with a good knowledge of basic electronics should be sufficient to allow adequate understanding of the material presented in this chapter.

The equipment discussed in this chapter incorporates both the air intercept system and the CW radar set group. The intercept system may work independently of the CW radar group as search or mapping radar, or it may be used in conjunction with a computer group as both a radar director system and a disturbed reticle (visual) system.

In the visual day fighter installation, the pilot acquires the target visually and flies the aircraft so as to keep the target in his gunsight. The essential companion equipment of the missile contains the following:

1. The illuminator radar, a small, low powered CW system that provides no automatic aiming features but which includes both transmitting and receiving functions.
2. The launching equipment, consisting of finite length launchers and pylons for underwing suspension of the missiles.
3. The necessary wiring and cabling, the cockpit controls and indicators, and the relays which operate the firing circuits of the weapons.

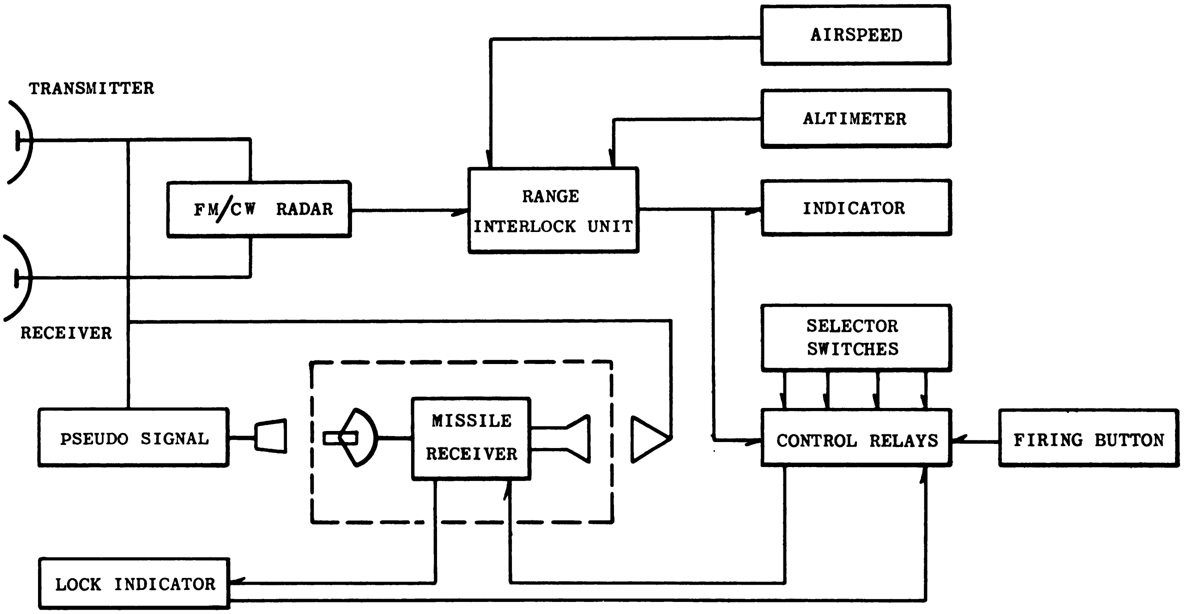

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Figure 14-1. –Block diagram of an illuminator installation.

The illuminator radar unit may be mounted in an external stores package such as a wing pod, or in the nose of the aircraft.

In all-weather fighter installations, the total equipment includes the same basic units in addition to an aircraft radar intercept (AI) system, usually of the pulse type. In the pulse AI installation, illumination of the target with CW radiation is accomplished by means of an auxiliary unit which injects the CW energy into the waveguide plumbing of the pulse radar. The principal components of a typical illuminator installation, which are associated with control of the missile, are indicated by the simplified block diagram in figure 14-1.

Upon acquisition of the target, the AI radar measures the closing speed and the target range and applies the information to the range interlock unit.

The range interlock unit receives the radar information and combines it with altitude and aircraft airspeed data to determine if the target is within the zone of effectiveness of the missile. If within this zone, the interlock is closed, allowing the missiles to be fired at the discretion of the pilot.

While the weapons are on the launching racks, the guidance circuits are placed in operation and the speed gate is locked on a pseudo signal generated by the CW radar system. Successful locking on this signal indicates proper operation of the missile guidance equipment and verifies that the receivers are tuned to the illuminator emissions. Failure to lock-on the pseudo signal by any missile will automatically hold fire on that particular weapon. When lock-on has been accomplished, a Sim-Dop signal is applied by the lock indicator to the missile relays; and this voltage, together with the enabling signal from the interlock unit, permits the pilot's firing button to energize the firing circuits.

At launch, the missile guidance receiver begins automatic search for the target, receiving the CW signals emitted by the illuminator radar both directly and by reflection from the object.

FUNDAMENTALS OF MISSILE GUIDANCE AND CONTROL

To have a better understanding of theproblems involved with effectively directing a missile to the target, the technician must become familiar with the fundamentals of missile guidance and control. Guided missiles differ from gun and rocket projectiles in that gun and rocket projectiles are committed to a given course at the instant of firing, while the course of a missile is altered during flight. The missile fire control problem must be continuously solved. To accomplish this, the four functions which must be performed are as follows: (1) tracking; (2) computing; (3) directing; and (4) steering.

The necessary components for the performance of all the functions may be located entirely within the missile itself, or some may be located in the launching aircraft. It should be apparent that the Aviation Fire Control Technician is primarily concerned only with those components located in the aircraft.

A precise comparison between the gun and rocket fire control problem and the missile fire control problem is difficult to make. In naval aircraft, the gun and rocket fire control problem is continuously solved from the start of the run until the projectile is fired; but the solution of the missile fire control problem continues until the missile strikes the target.

MISSILE FIRE CONTROL PROBLEM

There are three phases to the missile fire control problem; namely, prelaunch aiming, guidance, and control. Together they determine the proper flightpath for the missile and control the missile so that it follows this path.

Prelaunch Aiming Phase

The prelaunch aiming may be considered to be similar to the aiming problem for unguided weapons (guns and rockets), but with a wider tolerance for aiming errors. It might also be considered to be an essential part of the guidance phase.

Guidance Phase

The guidance phase of the missile fire control problem is concerned with that portion of the problem which determines the missile's course to the point of interception. The guidance system must perform three functions—tracking, computing, and directing. (NOTE: Guidance in semiactive homing usually involves the use of radar and computing equipment necessary to determine how a missile's course must be changed to intercept the target.)

Tracking is the process of continuously determining the relative positions of the target and the missile. Tracking may be done by visual observation, the use of radar, or any other process which utilizes some distinguishing feature of the target. The tracker may be located in the missile itself or in the launching aircraft.

Computing is the process of determining course corrections, both magnitude and direction, which the missile must make to score a hit. The computing system may be elaborate or simple, but all systems utilize tracking data received from the tracking system. The computing equipment may be installed in either the missile or the launching aircraft.

Directing, as the term implies, is the process of directing or telling the missile what course corrections must be made. The output of the computing system furnishes correction data which is transmitted to the missile's control system, to accomplish steering. A computing system, located in the launching aircraft, must transmit course correction data to the missile. Radio waves are normally utilized to complete the data transmission loop.

Control Phase

The control phase is concerned with the performance of the steering function previously mentioned. The steering function deals with the aerodynamic portion of the missile fire control problem which, when properly performed, provides smooth and stable flight of the missile. The steering function is performed by the control system consisting of equipment required for converting steering or guidance signals to movement of the missile's control surfaces. The control system is contained entirely within the missile itself and is of little concern to the Aviation Fire Control Technician except to provide a better understanding of the overall system.

METHODS OF GUIDANCE

In operations involving air to air missiles, the target is usually located a short distance from the launching platform when compared with the surface to surface missile operations. In most cases the target is also relatively small and highly maneuverable. Therefore, a guidance method is required that is capable of making continuous corrections to the flightpath and which can respond rapidly to changes in the position of the target. The guidance systems must be suitable for use with maneuverable launchers, since air launched missiles are carried either on pylons attached to the wing or on some enclosed or retractable mechanism.

The guidance methods most suitable for these conditions are the beam rider and the homing methods. The other guidance methods are the baseline and the self-contained; however, they are unsuitable and find limited application with airborne missiles.

Beam Rider Method

In the operation of the beam rider method the target is tracked by a radar beam (usually that of a radar set carried by the launching aircraft), and the missile responds to the beam by means of a receiver. The output of the receiver consists of error signals which, when applied to the control system, cause the missile to remain in the center of the radar beam until it collides with the target. Figure 14-2 illustrates the beam rider guidance method.

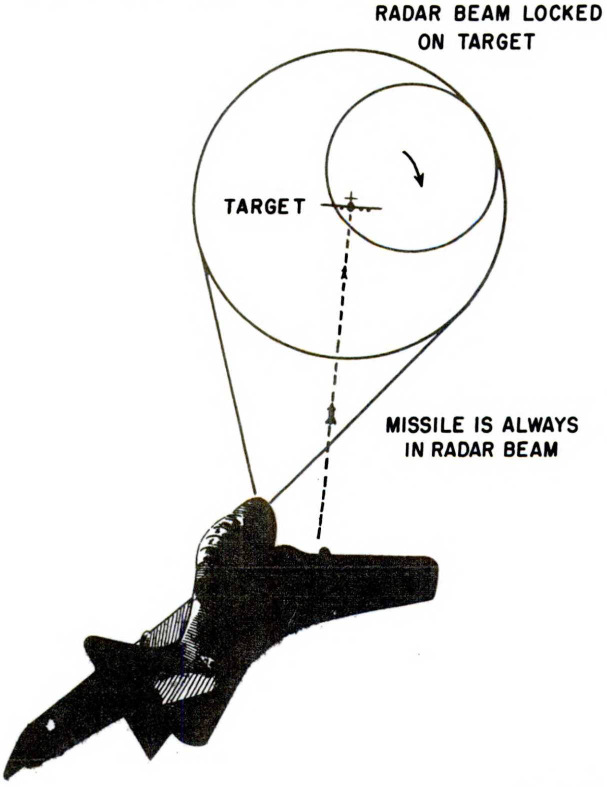

Figure 14-2. –Beam rider guidance method.

Missiles controlled by the beam rider method are subject to direct control by the launching aircraft radar. Once the target has been acquired by the aircraft radar, automatic tracking devices keep the radar beam continuously on the target. An automatic homing device may also be used to control the missile during the final stage of its flight.

Homing Method

With the homing method of guidance, the path of a missile can be changed, after launching, by a device in the missile that reacts to some distinguishing feature of the target–such as heat, light, or reflection of radar waves. A homing device, usually placed in the nose of the missile, picks out the target and then directs the missile to the target.

The best homing systems make use of heat radiation and reflection of RF energy. These systems are accurate, and the missile may be expected to hit its target if released within its range of operation.

Homing guidance systems are of three types–active, passive, and semiactive. In the active homing guidance system, both the transmitter, which illuminates the target, and the receiver, which receives the echoes, are carried within the missile. In the passive system, the missile utilizes radiations from the target. With the semiactive system, the receiver in in the missile utilizes radiations from the target, which has been illuminated by a transmitter located in the launching aircraft.

There are several ways in which the missile's homing device may control the path of the missile to a moving target. The more generally used systems are the pursuit homing and lead homing types, in which the course flown by the missile approximates that of a lead collision course.

In pursuit homing the guidance system causes the missile to point directly toward the target at all times. The homing device points directly ahead, and keeps the heading of the missile the same as the direction of the target echoes. A missile flying pursuit course experiences increasingly large "G" forces due to turning in to the last portion of the course, as shown in figure 14-3. This part of the flightpath is most critical; and unless the target is either large or flying a collision course, accuracy is greatly reduced. As a result, pursuit homing does not have many applications against high speed targets.

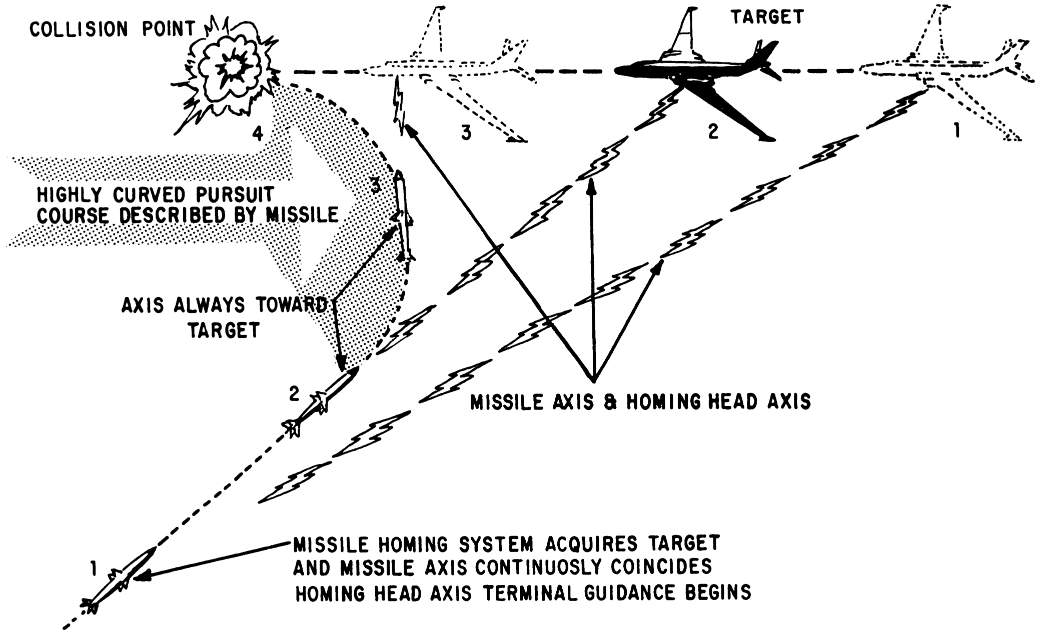
COLLISION POINT
TARGET
4
3
2
1
HIGHLY CURVED PURSUIT COURSE DESCRIBED BY MISSILE
3
AXIS ALWAYS TOWARD TARGET
2
MISSILE AXIS & HOMING HEAD AXIS
1
MISSILE HOMING SYSTEM ACQUIRES TARGET AND MISSILE AXIS CONTINUOSLY COINCIDES HOMING HEAD AXIS TERMINAL GUIDANCE BEGINS

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Figure 14-3.–Pursuit homing.

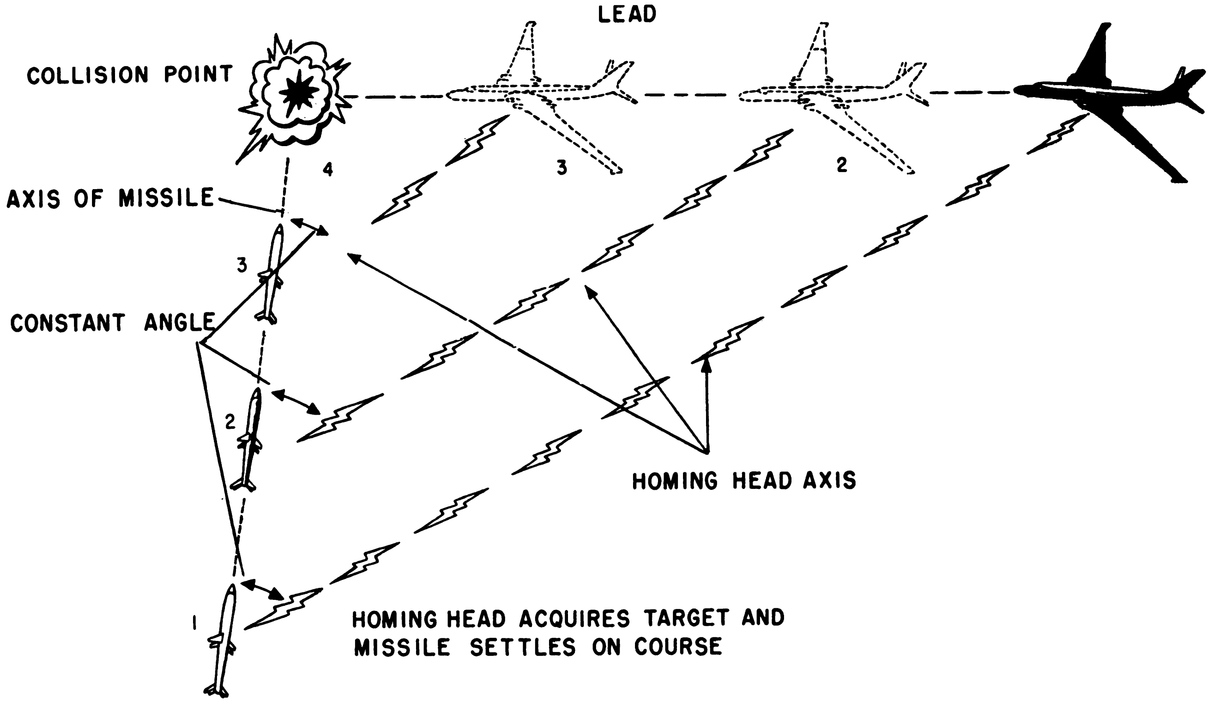

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Figure 14-4.–Lead homing.

In a lead homing, a lead collision course is established when the path of the missile maintains a constant angle with the path of the target. In lead homing, the guidance system establishes a lead angle with the target and keeps this angle essentially constant so that the missile travels directly toward a collision point, as shown in figure 14-4. This causes the missile to complete the final and critical part of the flightpath as a straight line.

To effect this course it is necessary for the guidance system to measure the rate at which the angle changes. This may be accomplished by having the homing device point toward the target; and any change in the direction of the target from the missile will cause the homing device to turn. The rate at which it turns can be measured by a rate gyroscope. These additional functions require that the homing system for a lead course be more complex than a system for a pursuit course.

One of the main limitations of homing systems is that of range. Also, homing devices must have high directional sensitivity so they will not be confused by multiple targets. Because of these problems, it is necessary to place the missile in the vicinity of the target and pointing toward the target. This may require the initial part of the course to be controlled by another type of guidance system, such as the beam rider system.

CW AND DOPPLER EFFECT

One of the missile guidance and control systems employed in aircraft utilizes the continuous wave (CW) radar method for illuminating the target. This method differs considerably from the pulse method of radar operation.

With CW illumination of the target, the missile receiver detects the presence of the target object by sensing its relative speed with the principal measurement being one of frequency difference. The basis of this measurement is the Doppler effect, a property of wave motion which has numerous applications in many fields of physics. The general nature of this effect and the characteristics which make it useful in missile systems are discussed in the following paragraphs.

The Doppler principle, first brought to notice in 1842 by an Austrian physicist, Christian Doppler, pertains to the shift, or change in frequency, that occurs when there is relative motion between the source and the receiver of a series of waves. The frequency shift takes place with all kinds of waves—sound, light, and the emissions of radio and radar transmitters. A simple example in terms of sound is familiar to anyone who has observed the change in pitch of a train whistle as it approaches or recedes rapidly. When approaching, the sound producing whistle comes a little nearer between each two successive waves it emits; and the waves strike the ear in a little more rapid succession, so that the frequency becomes greater and the pitch rises.

If the train is moving away from the observer, the interval between successive waves is slightly increased, the frequency received by the ear is somewhat decreased, and the pitch is lowered as a result. If the frequency of the sound received when the train is at rest is measured and compared with the value received when the train is in motion, there is a difference in the two values called the Doppler shift. This frequency difference could then be used to measure the speed of the train with respect to the observer.

A CW radar operates by means of the same effect except that electromagnetic waves are employed instead of sound. The transmitting antenna of the radar set beams uninterrupted, unpulsed energy of a given frequency upon the target. Upon reflecting the energy, the target becomes, in effect, a second emitter of waves; and if it is in motion with respect to the radar, the frequency of the returning echoes differs from that of the outgoing signals. The echoes are picked up by the receiving antenna and are heterodyned in the receiver with small reference voltages at the frequency of the outgoing waves. The difference value, or beat frequency, which results from mixing the reference and echo voltages, is the Doppler signal, the presence of which indicates a moving target. As in the example of the moving train whistle, the Doppler value in hertz serves as a measure of the relative speed.

In textbooks that deal with the Doppler effect, it is shown that in two-way travel of electromagnetic waves as in the CW radar system, the amount of frequency change in hertz (Hz) (f_D) is related to the relative speed (V) by simple equations,

$$f_D = \frac{2V\ f}{C} \qquad (1)$$

in which f is the frequency of the reference signal, and C is the velocity of the radar waves.

If the closing velocity is measured in miles per hour and if $C/_f$ is taken as the wavelength of the reference emission, the equation can be expressed in the following form:

$$f_D = \frac{89.4V}{I\ \lambda} \qquad (2)$$

where f_D is in hertz, V is in miles per hour, and the wavelength, λ, is measured in centimeters.

The factor 89.4 is explained as follows: The conversion of miles per hour to centimeters per second introduces the conversion factor 44.7. This is then multiplied by 2, as indicated in equation (1).

If the CW radar emits radiation with a wavelength of 10 centimeters, then according to equation (2), the Doppler signal will vary by almost 9 Hz for each increment in the closing or opening speed of 1 mile per hour. If the radiation has a wavelength of 3 centimeters, a typical value in microwave systems, then the Doppler shift amounts to almost 30 Hz for each increment in the closing or opening speed of 1 mile per hour.

The relation of signal frequency to velocity is illustrated in figure 14-5, which indicates the distribution of Doppler signals corresponding to three conditions of relative motion. The missile, employing CW radar guidance, flies at a velocity of V_M. For the aircraft approaching at velocity V_1, the missile circuits produce a Doppler signal proportional in frequency to the sum of V_M and V_1 because relative closing speed V equals V_M plus V_1. The signal of the crossing target is considerably less in frequency, being proportional at the instant shown to the missile velocity, V_M, because relative closing speed V equals V_M. The Doppler frequency of the receding target is determined by the difference between V_3 and the missile velocity, because relative speed V equals V_M minus V_3. If V_M is larger than V_3 then relative speed V is closing. If V_M is smaller than V_3 then relative speed V is opening.

With Doppler operation, the missile circuits are designed to exclude all signals except those contained in a fairly narrow frequency range called the speed spectrum of the system. This term refers to the range of Doppler frequencies corresponding to the possible closing speeds of the missile with the class of targets for which it is intended. For example, assume that for a certain air to air missile, the sum of V_M, the missile velocity, and V_1, the velocity of an approaching aircraft is 2,000 miles per hour and that this figure represents the maximum closing speed of the missile and any possible aircraft target. Assume further that the minimum possible closing speed is 100 miles per hour; and also that the radar system employs 3-centimeter radiation.

When these figures are substituted in equation (2), the resulting Doppler frequencies are 59,600 Hz for the upper speed and 2,980 Hz for the lower–a range of approximately 3 to 60 Kilohertz. The speed spectrum of this particular system would extend over a range including these and all intermediate frequency values, thereby including the Doppler frequencies of all valid aircraft targets.

The missile receiver contains frequency selective circuits that respond only to Doppler signals in the appropriate speed spectrum; and after selecting one target signal in this range, the tracking circuits lock-on and track the corresponding object "in speed." By restricting reception to the comparatively narrow band representing possible closing speeds, all interference and clutter frequencies outside the band are eliminated at the outset. Furthermore, the likelihood of the missile being jammed by enemy countermeasures is minimized, the signal to noise ratio is increased, and the ability of the guidance receiver to work with low level input voltages is improved.

However, not all interference can be eliminated by Doppler operation. Random noise, for example, occupies a frequency band which is extremely broad, and some noise energy necessarily appears in the speed spectrum. Also, as indicated in figure 14-5, some clutter return is present in the spectrum. Clutter occurs at frequencies lower than those of approaching aircraft Doppler signals.

To insure selection of a valid Doppler signal against a background of interference, the following method is often employed in CW missile systems. The carrier wave of the companion radar is modulated with at least two identifying, or coding, signals. One of these, when detected in the missile circuits, causes a

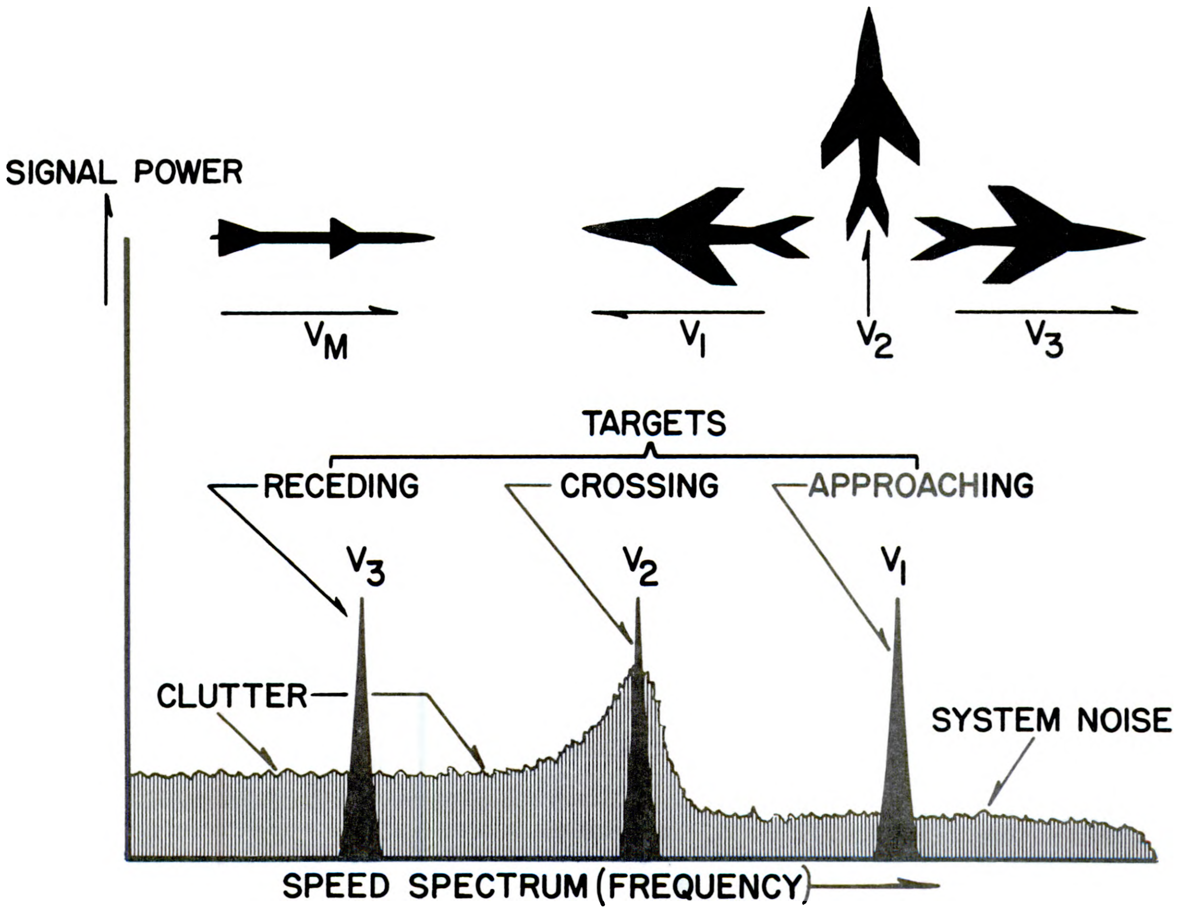

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Figure 14-5. —Doppler signals for various closing velocities.

section of the receiver to lock-on the beam of the correct parent transmitter so that the proper reference frequency for producing the Doppler signals is assured. The second coding signal provides a means for selecting valid Doppler voltages. Gating circuits in the receiver scan the speed spectrum, examine each signal in turn, and determine whether or not the identifying modulation is present in sufficient strength to indicate an aircraft target. Noise voltages and other signals which do not contain the coding frequency are rejected, while the valid signal, which contains the modulation, is passed on to the tracking circuits.

The application of Doppler methods to missile homing has produced guidance equipment which is superior to most pulse radar sets for operations against low flying targets because of the effectiveness of CW radar in working through interference and clutter.

COMPONENTS

The intercept system discussed in this chapter consists basically of a radar set and an armament control director. However, additional components are necessary for the operation of the system. Some of these components are supplied as a part of the system and some are supplied as aircraft equipment. Therefore, the discussion is in terms of the radar set and associated components. Figure 14-6 is a block diagram of the complete system. It should be noted that the system is divided accordingly. The block analysis of the radar set is by systems rather than by components or chassis.

Radar Set Group

The radar set group is a major unit of the radar set and consists of the receiver-transmitter, synchronizer, and power supply.

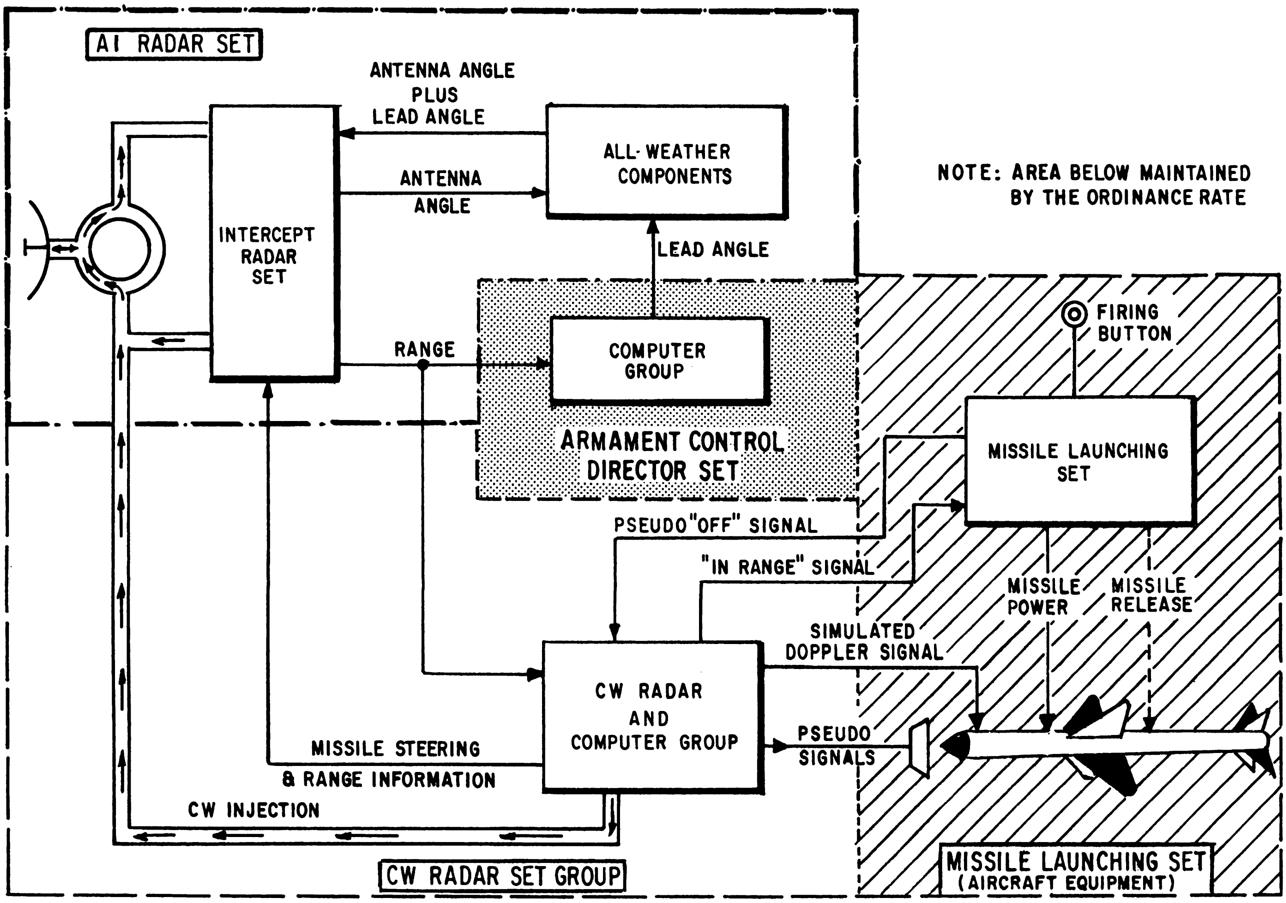

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Figure 14-6.–Block diagram of a typical system.

Each subassembly or chassis is mounted on a hinged assembly or pallet in a barrel shape. The entire assembly is arranged in a manner permitting removal for maintenance purposes, and each pallet is arranged so that it can be dropped away from the group to provide access to the subassemblies.

The armament control director (shaded portion of fig. 14-6) is mounted in the same structure but is not considered part of the radar set group. The same is true of the antenna assembly.

CW Radar Set

The CW radar set group is composed of four major units as follows:

1. Computer.
2. Modulator.
3. Power supply.
4. Transmitter and cooling system.

Each major unit is discussed briefly in the following paragraphs and is discussed in greater detail later in this chapter.

The computer receives and processes range and azimuth information from the AI radar. True airspeed and altitude pressure data are also received from the air data computer. The computer provides outputs of head-aim, English bias, and simulated Doppler for the missile. Range interlock information and aim dot (steering) information for the AI radar is also provided.

The MODULATOR provides the signals for modulation of the CW for coding, ranging, and identification of illuminating source; it also provides the pseudo signal for tuning the missile. The modulator contains an interlock for protection of the CW magnetron/klystron.

The HIGH-VOLTAGE POWER SUPPLY provides the filament and high voltage for the CW magnetron/klystron. It also contains a time delay circuit for delaying the high voltage to the CW magnetron/klystron and the 28 volts (delayed) to the klystron tuners.

The RADAR TRANSMITTER generates the CW-RF carrier signal and modulates the CW-RF for coding and ranging. The transmitter contains the necessary plumbing, filters, etc., and provides isolation from the AI pulsed radar. It also contains the CW magnetron/klystron cooling system, a closed system, which is used to dissipate the heat from the CW magnetron/klystron and associated parts. The pump continuously circulates the coolant as long as power is applied to the transmitter.

Associated Components

In figure 14-7, six associated components are illustrated, three of which are supplied as aircraft equipment. They are the flight data unit, vertical gyro, and the angle of attack and skid system. Each is essential to the operation of the intercept system. However, each is supplied as aircraft equipment because other equipment in the aircraft also depends on their outputs. Some of the components are discussed in in the following paragraphs.

The FLIGHT DATA UNIT contains climb and roll circuits, a true airspeed computer, and an air density computer. They are supplied information by the aircraft's pitot-static system and the vertical gyro. Figure 14-8 is a block diagram of the climb and roll section of the flight data unit (FDU).

The technician should recall that the vertical reference gyro and the computation of true airspeed and air density are discussed in Aviation Fire Control Technician 3 & 2. The theory of the resolution of gravity deflections is also discussed.

The RANGE ADAPTER is used only when a visual attack is being made on a target. It converts present range voltage received from the radar range tracking system to values of present range and range rate suitable for use by the computer group. Figure 14-9 is a block diagram of the range adapter.

Range rate information is supplied by the range rate computer section. This section is basically an RC differentiator of the feedback amplifier type. Most of the operating voltages are supplied by the radar power supply.

The ARMAMENT CONTROL DIRECTOR is essentially an electromechanical analog computer. It should be recalled that the director is split into two sections, a kinematics section and a ballistics section, and utilizes several servos in arriving at solutions for the problems presented to it. The director computes the following information:

1. Steering error singals.
2. Opening or closing range rate.
3. In-range signal.
4. Rocket launching signal.
5. Collision warning signal.

The ANGLE OF ATTACK AND SKID SYSTEM is shown in figure 14-10 in block diagram form. It should be remembered that it is part of the aircraft equipment and is discussed briefly in this chapter.

The angle of attack and skid system is an electomechanical analog computing system which provides true angle of attack and skid information for use by air to air rocket and gun firing fire control system. The principal channels of signal flow through the system are shown in the functional block diagram in figure 14-10.

The computer group usually associated with the type of missile control system discussed in this chapter is centered around an electromagnetic computer of the type discussed in chapter 15 of Aviation Fire Control Technician 3 & 2. Therefore, no detailed discussion of the computer group is included in this chapter.

PHASES OF OPERATION

In general, the operation of the system may be classified under four phases with each phase having one or more modes of operation. The phases of operation are standby, search, acquisition, and track. Each phase of operation is essential to the radar in accomplishing its purpose. The phases and modes of operation are summarized in table 14-1.

Standby

During the standby phase of operation the radar set and the associated components illustrated in figure 14-7 are supplied with filament voltages and control voltages as required and are ready for full operation after an initial delay.

Search

During the search phase, the system provides radar search capability for assisting the

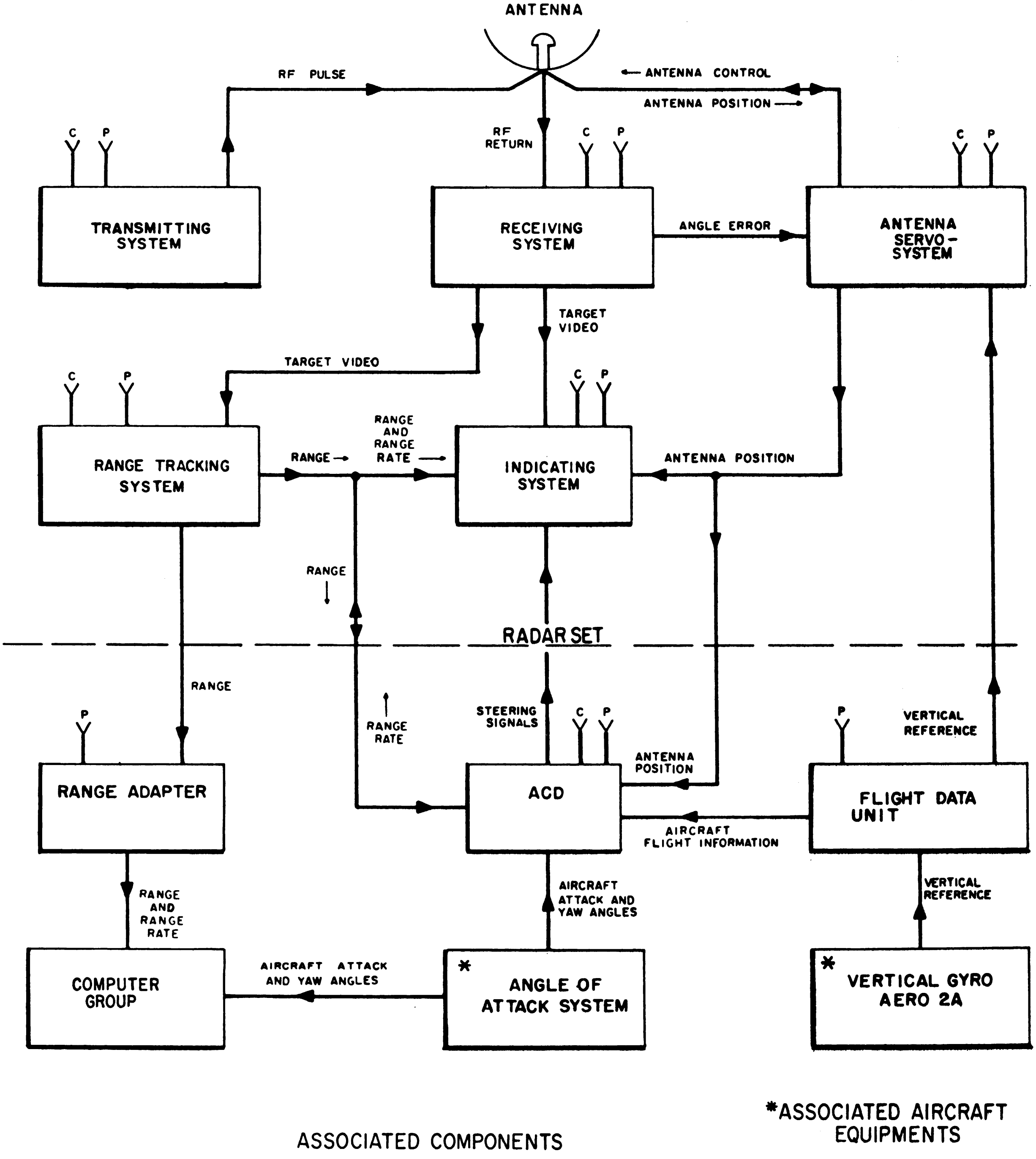

Figure 14-7. –Block diagram of a typical intercept system and associated components.

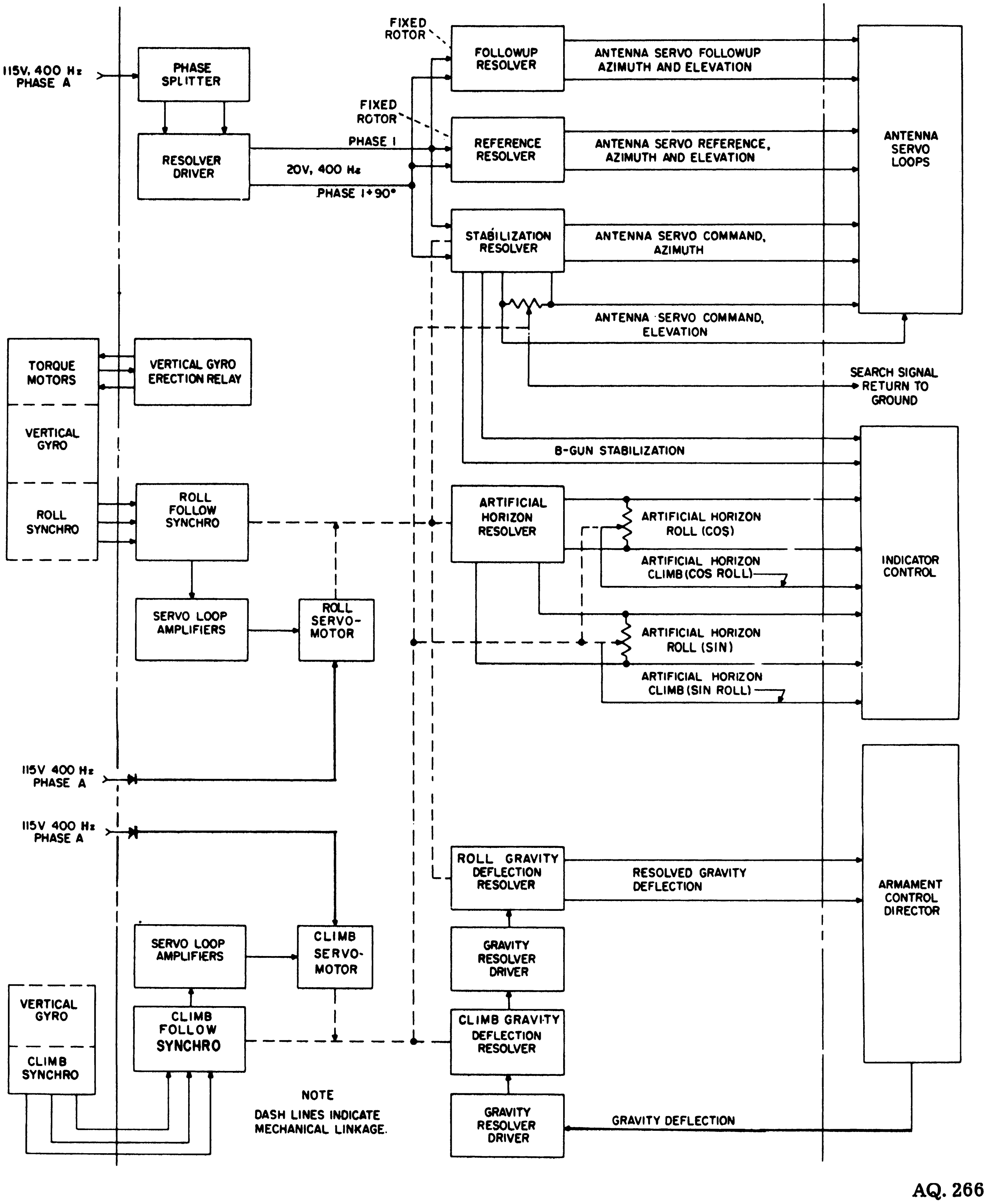
115V, 400 Hz
PHASE A
PHASE SPLITTER
RESOLVER DRIVER
FIXED ROTOR
FIXED ROTOR
PHASE I
20V, 400 Hz
PHASE I+90°
FOLLOWUP RESOLVER
REFERENCE RESOLVER
STABILIZATION RESOLVER
ANTENNA SERVO FOLLOWUP AZIMUTH AND ELEVATION
ANTENNA SERVO REFERENCE, AZIMUTH AND ELEVATION
ANTENNA SERVO COMMAND, AZIMUTH
ANTENNA SERVO COMMAND, ELEVATION
ANTENNA SERVO LOOPS
SEARCH SIGNAL RETURN TO GROUND
B-GUN STABILIZATION
TORQUE MOTORS
VERTICAL GYRO ERECTION RELAY
VERTICAL GYRO
ROLL SYNCHRO
ROLL FOLLOW SYNCHRO
SERVO LOOP AMPLIFIERS
ROLL SERVO-MOTOR
ARTIFICIAL HORIZON RESOLVER
ARTIFICIAL HORIZON ROLL (COS)
ARTIFICIAL HORIZON CLIMB (COS ROLL)
ARTIFICIAL HORIZON ROLL (SIN)
ARTIFICIAL HORIZON CLIMB (SIN ROLL)
INDICATOR CONTROL
115V 400 Hz
PHASE A
115V 400 Hz
PHASE A
ROLL GRAVITY DEFLECTION RESOLVER
RESOLVED GRAVITY DEFLECTION
ARMAMENT CONTROL DIRECTOR
GRAVITY RESOLVER DRIVER
SERVO LOOP AMPLIFIERS
CLIMB SERVO-MOTOR
VERTICAL GYRO
CLIMB SYNCHRO
CLIMB FOLLOW SYNCHRO
CLIMB GRAVITY DEFLECTION RESOLVER
GRAVITY RESOLVER DRIVER
GRAVITY DEFLECTION
NOTE
DASH LINES INDICATE MECHANICAL LINKAGE.
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Figure 14-8. –Block diagram of the climb and roll section of the FDU.

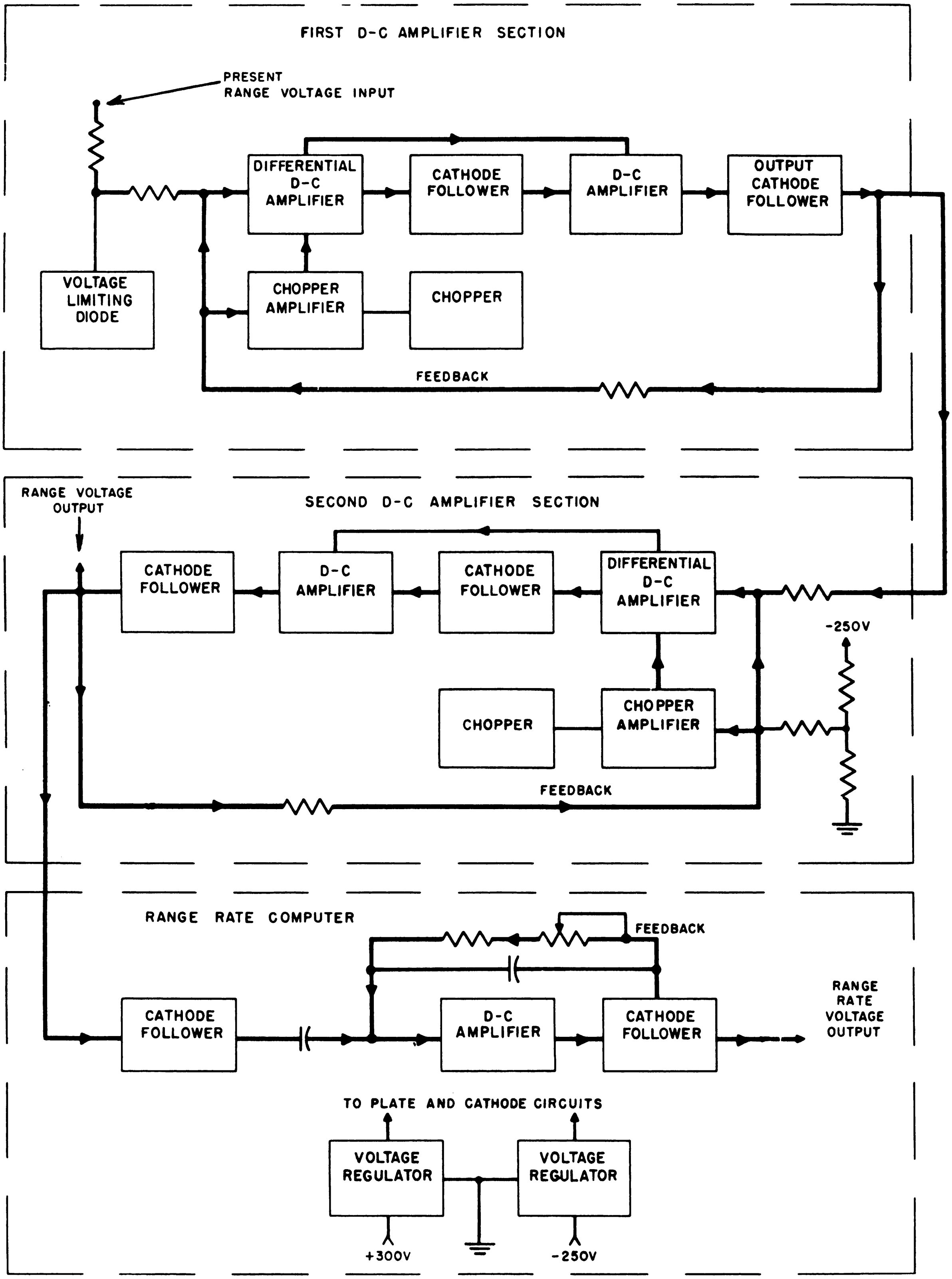

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Figure 14-9. –Range adapter block diagram.

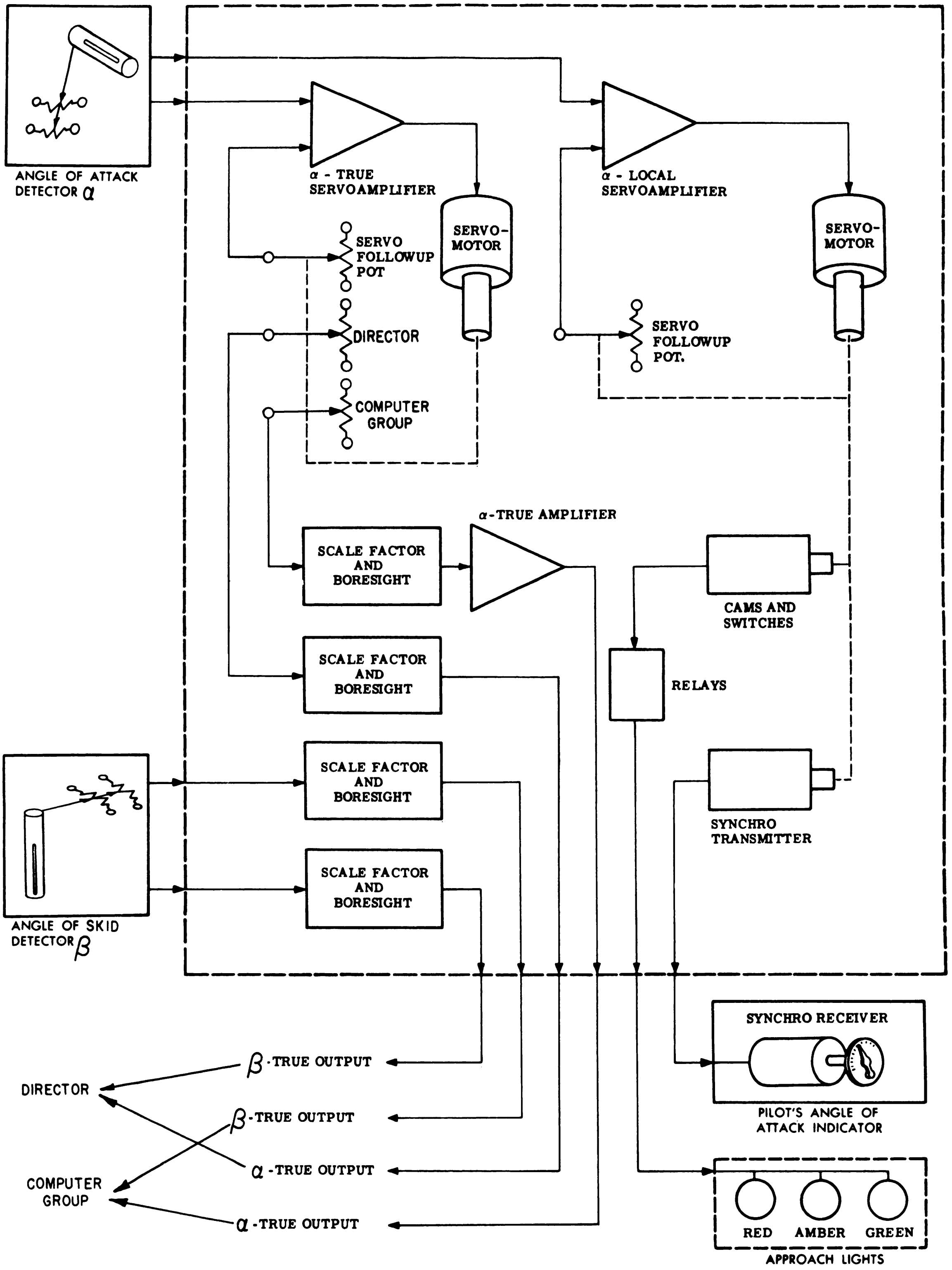

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Figure 14-10. –Angle of attack and skid system.

Table 14-1.–Phases of operation.

Phase	Mode	Comments
Standby		Equipment warmup.
Search	AIR INTERCEPT	Radar searches forward area.
	MAPPING	Radar searches surface area.
Acquisition	NORMAL	Target lock-on.
	ARO	Lock-on when target reaches selected range.
Track	Air to air	Radar track.
	Lead pursuit–guns or rockets	Manual firing.
	Lead collision–rockets	Automatic firing.
	Pure pursuit–missile	Director inoperative (ACD).
	Air to surface	Radar not in use.
	Visual–all weapons	

pilot in navigating to the target area, locating the target, and (with special additional equipment) identifying the target. The orientation of the antenna or selection of the sector to be scanned is accomplished by the antenna control. The received or detected targets are displayed on a B-type presentation.

The radar set, when in this phase of operation, may operate in either the air intercept or mapping mode. In the air intecept mode the antenna scans the forward area as determined by the setting of the radar set controls. In the mapping mode, the antenna is tilted downward to obtain ground returns. Thus, the radar searches the earth's surface and the indicator displays a maplike presentation.

Acquisition

Upon identification of the target, the operator places the system in the acquisition phase. In this phase the radar locks on the target selected and begins to track. Thus, the system is in the attack phase and automatically tracks the target throughout the duration of the attack.

The system may be operated in either of two modes in the acquisition phase–NORMAL or ARO. In the normal mode, the target is selected for tracking by bracketing it with a pair of range strobes, positioning the azimuth strobe above the target position, and pressing the lock-on switch. Then the antenna slews to the determined azimuth position and lock-on occurs when the range strobe sweeps out and meets the target.

In the ARO mode, the antenna points dead ahead and the range strobes are set for the range at which the operator wishes to lock on the target. With the target lines up in the fixed reticle of the optical sight unit, the radar automatically locks on when the selected range is reached.

Track

As illustrated in table 14-1 the modes of equipment operation during the track phase are classified under two types of attack. The types of attack are air to air and air to surface. The distinguishing factor between the two is the use of radar in an air to air attack but not in the air to surface attack. Therefore, the only mode of operation in the air to surface operation is the VISUAL mode. In the air to air type of attack there are three primary modes of operation which are determined by the type of course to be flown and the weapon to be used. The three modes and lead pursuit (guns or rockets), lead collision (rockets), and pure pursuit (missiles). (NOTE: The visual mode may be employed in the air to air type of attack also.)

In the air to air modes, the radar set tracks the target continuously and supplies azimuth, elevation, and range information to the armament control director. The director computes steering signals and firing range information for display on the radar indicator in a C type presentation. The pilot then maneuvers the aircraft accordingly. Although the radar tracks the target automatically, he must fire the rockets or guns manually if on a lead pursuit course.

When making a pure pursuit course attack, the armament control director is inoperative and the indicator is supplied directly with target range and bearing information. Also during the attack phase, the task of notifying the pilot when the target is within firing range and presenting anticollision warnings is accomplished by indications initiated in the armament control director or computer group.

PRINCIPLES OF OPERATION

The radar set (fig. 14-7) operates on principles similar to those of any other airborne radar set. The essentials of the set consist of an RF transmitter, antenna, a receiving system capable of detecting the RF energy reflected from the target, an indicator(s) and a synchronizer. The energy developed by the transmitter is radiated by the antenna as a series of very short powerful pulses. During transmission the receiver is made inoperative by the duplexer which permits the use of a single antenna by the sensitive receiver and a high power transmitter. Upon completion of each transmission the receiver amplifies the weak pulses returned by the target and reproduces them as video pulses to be applied to the indicator(s).

The indicator(s) produces a visual indication of the echo pulses in a manner which furnishes the required information about the target. The synchronizer supplies the synchronizing signals, which time the transmitted pulses and the indicator(s) providing a means of measuring the time interval between the transmission of the energy and its return as a reflection. Since RF energy travels at a constant velocity, the time interval becomes a measure of the distance traveled or range. Target direction information is obtained by using a highly directional antenna which radiates in a very narrow conical beam.

Search Operation

During search operation the beam is moved rapidly through a scanning pattern which covers a sector centered in azimuth about the centerline of the aircraft with a vertical beam width equal to approximately twice the conical beam. The position of the antenna when the target is located indicates its direction. The radar beam is nutated at a rapid rate, generating a conical pattern which is sector scanned in azimuth and jump-stepped in elevation at the end of each sector scan.

The antenna can be tilted to scan any sector desired in elevation, within the limits of the equipment by moving the antenna control fore or aft. The limits of the equipment extend equally above and below the armament datum line. A narrow scan sector, which covers about one-third the area of wide scan, may be selected when it is desired to concentrate on a particular area. The radar operator may move the antenna control to the right or left to position the scan sector in azimuth.

All targets within the scan area (up to the selected range of the radar) received during air intercept (AI), search, or mapping operations appear on the radar indicator(s), which utilizes a B-type presentation. The B-scan plots range against azimuth, with vertical displacement from the bottom of the scope representing range and horizontal displacement from the center of the scope representing azimuth. The position of the vertical B sweep is alined with the position of the antenna in azimuth and follows the position of the antenna as it scans.

To prevent loss of targets during the maneuvers required in normal search operation, the search pattern is stabilized. Position signals furnished by the vertical gyro are fed to the antenna servosystem to displace the antenna scan position when the aircraft deviates from straight and level flight. (See fig. 14-11.) When the aircraft is banked, the antenna is tilted in the opposite direction to maintain the scan parallel to the horizon. Similarly, when the

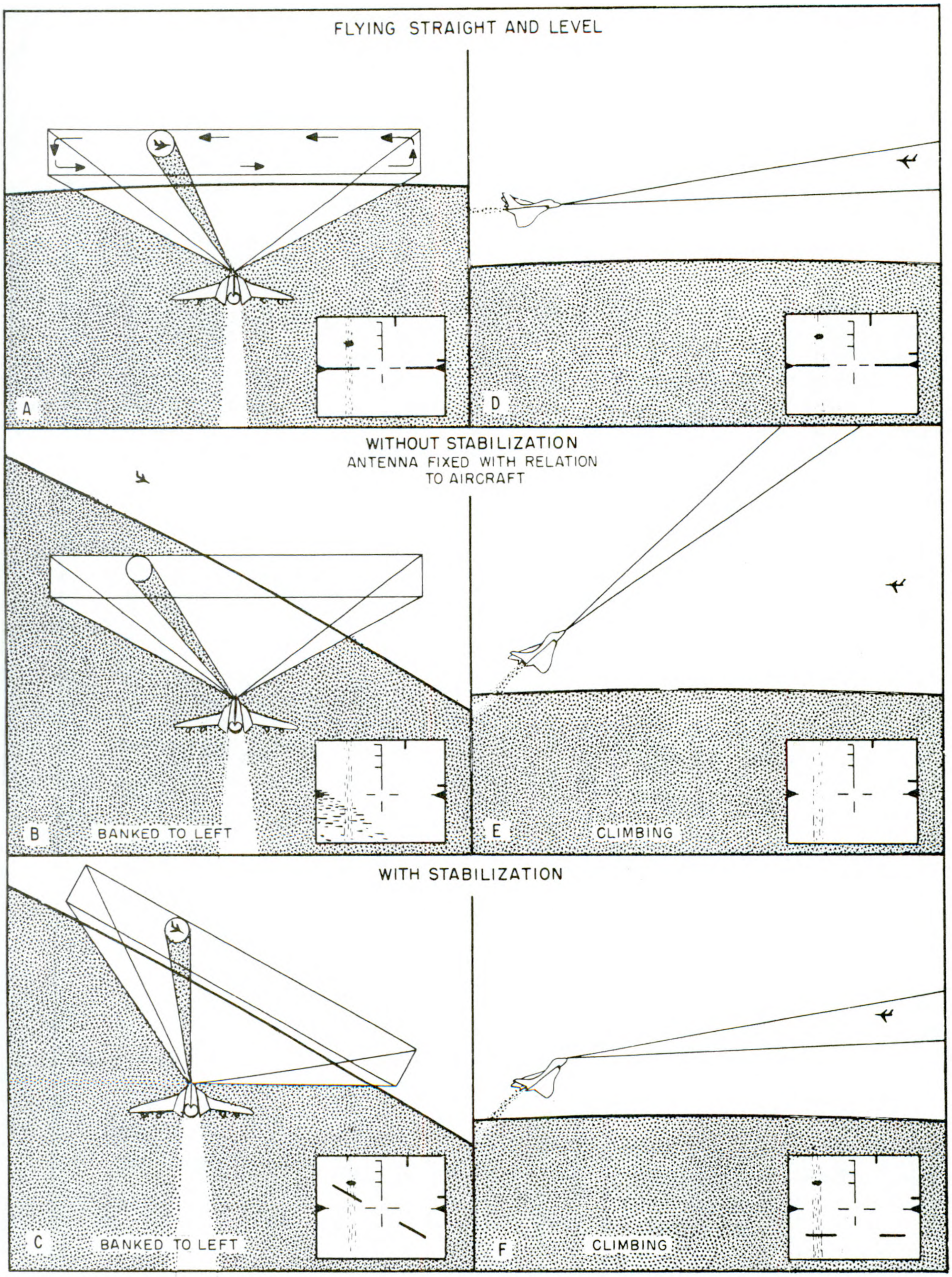

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Figure 14-11. –Effect of antenna stabilization.

aircraft commences a climb or dive, the antenna scan tilts to maintain the elevation position with respect to the horizon as set by the pilot.

Combined roll and climb or dive results in a corresponding displacement of the antenna scan in the opposite direction. Thus, the position of targets on the scope is changed only by a change in relative azimuth bearing and range. The effect of banking and climbing with no stabilization is shown in (B) and (E) of figure 14-11. Note the loss of target on the scope.

Since the antenna scan and the artificial horizon line on the scope are positioned by the same signals from the vertical gyro, displacement of the scan can be visualized by observing the artificial horizon line.

For mapping, the antenna is tilted slightly downward to pick up ground returns, and the indicator(s) displays a map of the forward ground area. The scan limits are the same as for air intercept.

Acquisition Phase Operation

The short transitional period between search and attack operation, when the target is being selected and locked on, is called the acquisition phase. When a target on the search presentation has been identified as an enemy, the radar operator initiates radar tracking by one of two methods.

In the first method, the radar operator positions a strobe on the radar indicator at the target's azimuth position, brackets the target with a pair of range strobes, and then presses the lock-on switch. This causes the antenna to cease scanning and point toward the target. This method also gives the radar operator complete manual control over the position of the antenna. From this point until lock-on occurs, the radar completes the acquisition automatically unless the target was not centered accurately in the radar beam initially. In this case, a slight repositioning of the beam by means of the antenna control is necessary. Usually the complete process by this method takes only a few seconds.

Track Operation

When conditions permit, the visual mode may be employed by the pilot during the track phase to carry out either the air to air or air

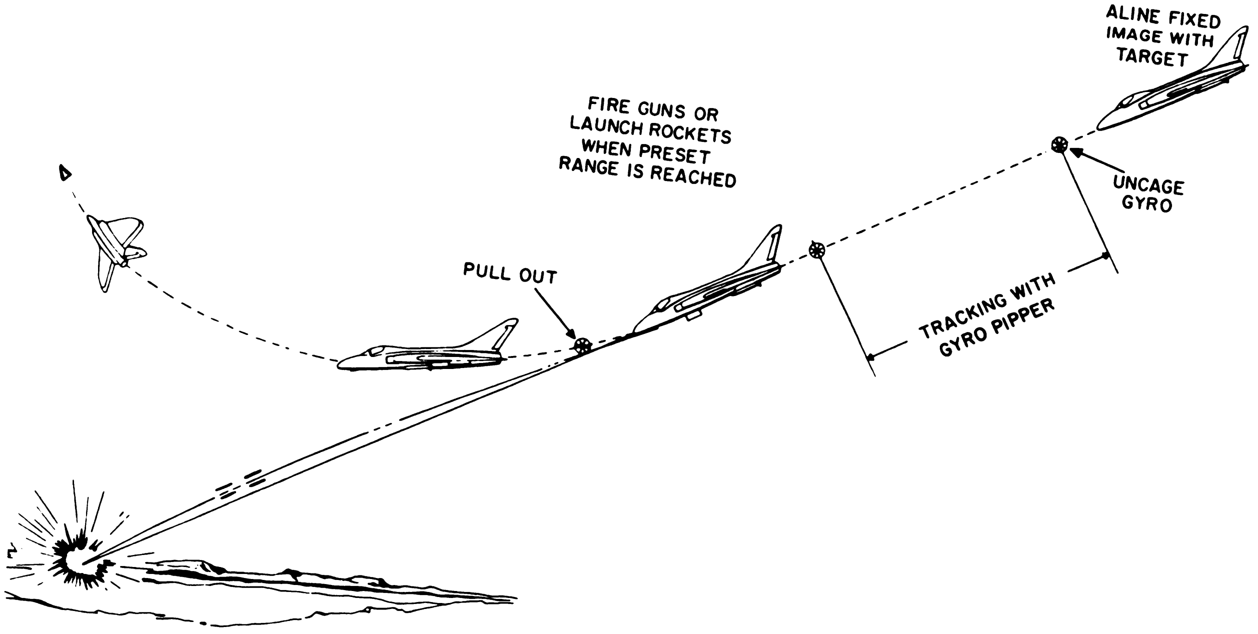
ALINE FIXED IMAGE WITH TARGET
FIRE GUNS OR LAUNCH ROCKETS WHEN PRESET RANGE IS REACHED
UNCAGE GYRO
PULL OUT
TRACKING WITH GYRO PIPPER

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Figure 14-12. –Air to surface attack.

to surface attack with guns, rockets, or missiles. However, the most practical application of the visual mode is in the air to surface attack. Figure 14-12 is an illustration of an air to surface type of attack.

During the visual mode of operation the lead angle is computed by the disturbed reticle system which was discussed in chapter 15 of AQ 3 & 2.

During the lead pursuit mode of operation, signals from the radar set control initiate lock-on. After lock-on occurs the radar tracks the target and the armament control director provides the solution to the fire control problem. During tracking, the antenna measures the direction and the angular rate of change of the target. At the same time, the radar signals are used to determine the present range.

Present range is the difference between this computed lead angle and the actual lead angle being flown by the interceptor (as measured by the tracking antenna) that is supplied by the director to the scope(s) in the form of deflection voltages to cause the circle and dot to be off center. Thus as the pilot centers the circle and dot presentation by maneuvering the interceptor, the computed lead and the actual lead are made equal and the steering error becomes zero. In some systems, the circle is not used. As the target comes to within range of the armament, the weapons are fired manually by the pilot as he depresses the gun or rocket firing button.

In addition to computing deflection signals for the steering presentation on the radar indicator(s) the director performs other supplementary functions. In-range warning is provided by the lighting of a lamp on the indicator and/or an audible tone applied to the pilot's headset when the interceptor is approaching a range where the time of flight of the shells or rockets is short enough to insure accurate firing. Anticollision warning is provided to warn of imminent collision of interceptor and target. A lamp on the indicator(s) is lighted and a breakaway signal is added to the scope(s) presentation.

In the lead collision mode the attacker flies essentially a straight line course toward the impact point of the projectile and the target. Since there is only one firing point on a lead collision course, rockets are used in order to provide sufficient firepower to insure a high kill probability. The rockets are automatically launched at the proper instant during the attack run in accordance with the future range preset by the pilot. The intercept system will direct lead collision attacks accurately from any angle off the target.

In lead collision attacks, the system functions nearly the same as in lead pursuit, except that the future range is preset at a single value rather than being computed continuously as in lead pursuit. The firing signal is also provided by the director.

In the pure pursuit mode the interceptor flies a course on which the antenna boresight line is always pointed directly at the target. After radar lock-on, the pilot can use either the steering dot on the radarscope or the fixed reticle of the optical sight to fly a pure pursuit course. The various stages of a pure pursuit course for a missile launch are shown in figure 14-13.

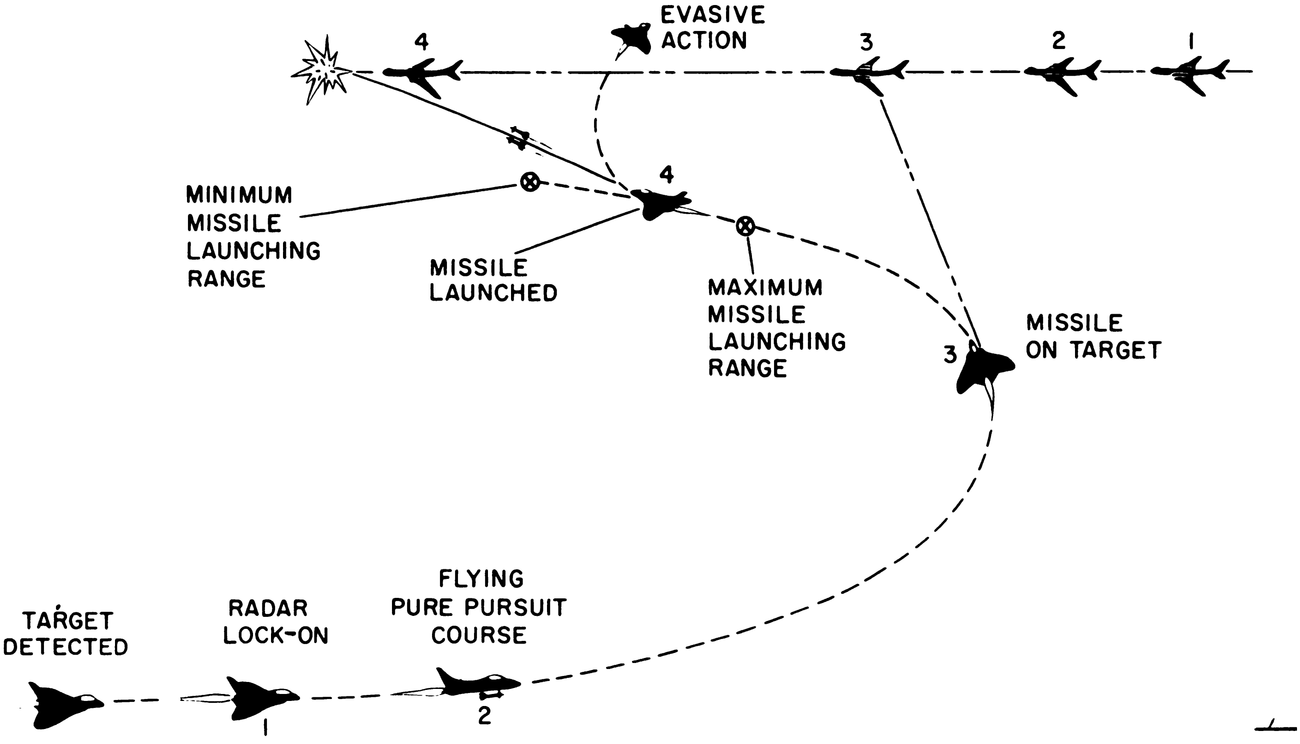
The following four major requirements must be fulfilled before missile launching can take place.

1. The interceptor must be flying a pure pursuit course.
2. The missile seeker must be on target.
3. The target must be within the minimum and maximum launching ranges of the missile.
4. The interceptor bank angle must be within established limits for the altitude at which the attack is taking place.

Once lock-on is initiated, the computing circuits of the director system are disabled so that the steering signals furnished the radarscope represent the output of the computer. (This information is the result of antenna angle and antenna angular rate which are received from the antenna resolvers.) Thus, if the aircraft is flown to maintain the steering dot at the center of the scope, the antenna boresight line of the aircraft will always be pointed at the target and the resulting course generated will be a pure pursuit course.

Once established on a pursuit course, the pilot will be informed as to the missile status. In the case of a heat seeking missile he receives a tone when the missile is locked on target. In the case of the Sparrow, he has a light indication on his missile status panel indicating his ready missile. The minimum and maximum missile launching range is a function of several factors, the most significant of which is altitude.

Prior to launch, the missile is fed head-aim and English-bias which will preset the initial course of the missile from after launch until the guidance system takes over.


EVASIVE ACTION
4
3
2
1
MINIMUM MISSILE LAUNCHING RANGE
MISSILE LAUNCHED
4
MAXIMUM MISSILE LAUNCHING RANGE
3
MISSILE ON TARGET
TARGET DETECTED
RADAR LOCK-ON
FLYING PURE PURSUIT COURSE
1
2

AQ. 271

Figure 14-13.—Pure pursuit attack for missile launch

When all conditions for launching are satisfied, the pilot presses the firing button to initiate missile launch.

INTRODUCTION TO A TYPICAL SYSTEM

Naval aircrafts are currently being equipped to launch supersonic guided missiles which employ the CW radar homing principle. A typical system capable of solving the missile fire control problem is illustrated in figure 14-6. It consists primarily of two items, as follows:

1. An intercept system consisting of an intercept pulsed radar and a computer group.
2. A CW radar group.

Additional components may be required to make up the complete system; for example, a flight data unit, a vertical gyro unit, and a launching set.

Before the guided missile can be launched, the missile control system must supply the missile with certain data. The intercept radar set determines range and develops a proportional voltage which is supplied to the computer group and the CW radar group. (NOTE: The computer group generates lead angle information for firing guns and rockets and is not used during a missile attack.)

The CW radar group generates CW-RF energy which is injected into the waveguide assembly and transmitted by the intercept radar antenna.

The CW radar also develops a pseudo signal which is fed to the missile for the purpose of checking the operation of the missile's circuitry to the Doppler frequency region. When the target is within range, the pseudo signal is cut off. Now the CW radar group develops a simulated Doppler signal proportional to the closing range rate. This simulated Doppler signal is fed to the missile to tune the missile circuitry to the anticipated Doppler frequency region. It should also be noted that the CW radar supplies in-range information to the missile launching set.

In order to understand the operation of the various functions of the system after launching, the use of the CW radar is discussed first. Figure 14-14 illustrates a typical missile attack problem. As shown, the CW signal is transmitted by the intercept system's antenna

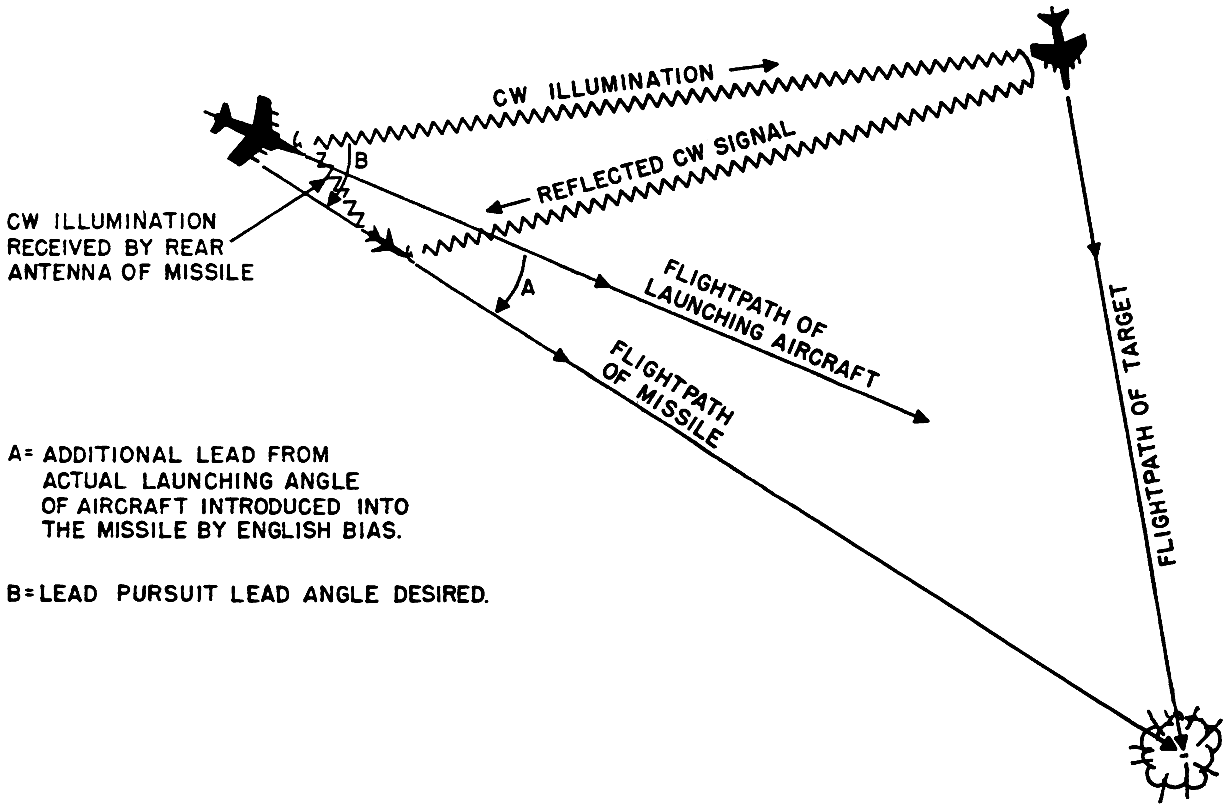

CW ILLUMINATION
REFLECTED CW SIGNAL
B
A
CW ILLUMINATION RECEIVED BY REAR ANTENNA OF MISSILE
FLIGHTPATH OF LAUNCHING AIRCRAFT
FLIGHTPATH OF MISSILE
FLIGHTPATH OF TARGET
A= ADDITIONAL LEAD FROM ACTUAL LAUNCHING ANGLE OF AIRCRAFT INTRODUCED INTO THE MISSILE BY ENGLISH BIAS.
B= LEAD PURSUIT LEAD ANGLE DESIRED.

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Figure 14-14.—Typical attack problem.

and, when reflected by the target, is received by the missile's nose antenna.

The rear missile antenna receives the CW signal directly from the intercept radar antenna, and then both signals are compared in the missile's receiving system. Because the distance between the missile and the target is decreasing, the signal received from the target is changed in frequency with respect to the signal received directly from the intercept antenna. The difference between the two is the Doppler frequency which is directly proportional to the closing speed.

The Doppler signal is applied to the speed gate where it is compared to a reference signal. The speed gate prevents the missile from homing on some other object near the target but moving at a different velocity. Steering signals are provided within the missile by deriving error signals from the conical scan antenna when homing on the reflected CW energy from the target. The missile uses the constant look angle method of homing on a target. Coding and range modulation are used to prevent interference and to measure the range to the target.

The intercept radar is used to detect and track the aircraft targets. At the time of launch the intercept radar antenna position information is fed to the missile's nose antenna for the purpose of properly positioning it for target acquisition. Head-aim and English-bias information is provided to the missile that will insert any correction required in the event the launching aircraft is not on the exact lead pursuit course. After the intercept radar has locked on a target and the missile to be fired has been selected and armed, the pilot can fire the missile when the in-range signal comes on, provided his target is within the ASE (allowable steering error) circle.

As illustrated in figure 14-14, the lead pursuit course which the launching aircraft attempts to fly is shown by angles B. Because of limitations in aircraft performance or heading errors on the part of the pilot, the aircraft may not be able to fly an exact lead pursuit course.

In this event a heading correction voltage (head-aim and English bias) proportional to angle A is supplied to the missile prior to launching in order to bring it on course immediately after launching. The heading correction is a d-c voltage generated in the CW radar group and provided to the missile, but used by the missile only after it has been launched.

INTERCEPT SYSTEM

The intercept system is used primarily for launching gun and rocket attacks on selected targets, or for the launching of guided missiles when associated with a CW radar group and a missile launching set.

The intercept system may be operated as a visual sighting system with the radar providing range and other target data to the computer group.

The system also provides a means of aiming the aircraft when, due to weather or lighting conditions, the target is invisible to the pilot. The radar provides an indicator that shows the target position, range, and range rate for the pilot's observation.

Modes of Operation

The modes of operation for the all-weather intercept system's radar set are automatic search, manual search, and automatic track. However, modes for the complete all-weather system are visual, alternate, and all-weather.

RADAR SET MODES.–During the automatic search mode of operation the antenna scans in azimuth a selected sector ahead of the aircraft as determined by the setting of the azimuth scan switch on the radar set control. The elevation angle of the scan pattern may also be controlled from the radar control panel. The indicators display pattern presented in the automatic search mode consists of the following:

1. The range sweep, which moves back and forth with the antenna motion.
2. The elevation strobe, which indicates the elevation angle of the antenna.
3. The target acquisition marks, which are used to select the desired target for lock-on.
4. The artificial horizon, which indicates the aircraft attitude in relation to the horizon.

Targets appear as bright spots on a B-type display. The maximum range at which targets may be detected is determined by the setting of the range switch on the radar set control.

The manual search mode of operation is used to spotlight the target and to establish target lock-on. To place the system in manual search, the action switch on the antenna control is held down, transferring control of the antenna position to the radar operator. The antenna hand control then positions the antenna so that the radiated beam is directed at the target as indicated by maximum brightness of the target echo. The range gate is positioned on the target echo by moving the gate out along the sweep or range trace. When the gate and the target echo are superimposed, the range lock-on occurs.

During the automatic track mode of operation, the antenna automatically follows the tracked target. The attack display provides the pilot with the following information: The direction in which to steer the aircraft to intercept the target, the opening or closing rate, and an accurate indication of the target range.

The steering information is presented in the form of an error circle and an error dot. Some of the later systems do not utilize the error circle, only the dot. The position of the error circle with respect to the center of the indicator screen indicates the amount and direction of azimuth and elevation error; i.e., the difference between the interceptor's heading and elevation angle, and the correct heading and elevation angle to score a hit. The error dot presents the same information as the error circle, but the deflection of the error dot is considerably greater for a given error in azimuth and elevation. On the later systems, the error circle indicates the firing limitations on the missile in both azimuth and elevation, and is centered on the scope presentation. It is known as the ASE (allowable steering error) circle.

Range information is presented in the form of a range circle which is centered on the indicator and becomes smaller as the range decreases. A small gap in the periphery of the range circle indicates the relative speed between the interceptor and the target. A clockwise position of the range rate gap indicates a closing rate and a counterclockwise position indicates an opening rate. Zero rate is indicated at the 12 o'clock position.

INTERCEPT SYSTEM MODES.–The modes of operation of the intercept system in no way alter, change, or modify the modes of operation of the radar set which were discussed in the previous paragraphs. The system is essentially a visual system, but the addition of the gyro and the converter to the system give it all-weather capabilities. With those components incorporated, the system has three modes of operation–visual, alternate, and all-weather.

In the visual mode of operation, the converter and gyro are used but the attack is made on the target visually; i.e., by observing the point of aim in the optical sight unit. The radar indicator presents lead information; however, it is slightly in error because no correction has been introduced for the sight unit dome temperature. Thus, the radar is useful in homing to within attack range of the target prior to making a visual attack.

During the all-weather mode, the gyro and the converter are also functioning. In this mode the dome temperature correction is introduced and lead information presented on the radar indicator is correct. Thus, an accurate attack can be made by observing the indicator. The steering circle and dot now represent the difference between the target and the computer lead angle. The interceptor should be turned so that the steering circle approaches the center of the indicator as the attack is made on the target. Correct lead is indicated when the steering circle and dot are centered on the indicator.

During the alternate mode of operation the gyro and converter are not used. In this mode the steering circle and dot on the indicator represent the relative position of the target to the aircraft. The optical sight will, however, present the correct lead angle. Thus, the pilot may make a pure pursuit attack by observing the radar indicator, or a lead pursuit attack by observing the optical sight unit.

Functional Operation

The radar has ten operational functions, consisting of the transmitting, receiving, radar ranging, computing, range sweep, antenna tracking, antenna positioning, commutation and blanking, attack display, and service functions. These functions may be grouped into six operational systems.

A block functional analysis of the radar set, including the computer group and all-weather components, is shown in figure 14-15. The relationship and functions of the various components are shown along with their major inputs and outputs. The operation of the system is essentially the same as other intercept systems. However, some differences in relation to missile capabilities should be noted.

The provision for CW injection into the waveguide from the CW radar group should be noted. In addition, an output of range is provided for the CW radar from the ranging function. Missile range and steering information are received from the CW radar group by the attack display function for presentation on the indicator.

TRANSMITTING FUNCTION.– The transmitting function generates RF energy, radiates it into space, and produces timing pulses for synchronization of the radar set. The transmitting function consists of a synchronizing channel, RF generating channel, and a transmission channel.

RECEIVING FUNCTION.– The receiving function converts the target echo signals intercepted by the antenna to an intermediate frequency, detects the video, and applies it to the CRT/DVST indicator. The function consists of the receiving channel (essentially the same as the transmission channel), signal IF channel, AFC channel, video channel, and the indicator channel.

RADAR RANGING FUNCTION.–The ranging function tracks a selected target and provides range information to the range circle channel, the computer, and the CW radar group. To initiate automatic track, the radar operator (RIO) manually positions the antenna to illuminate the desired target. By manipulation of the switch on the antenna hand control, the radar operator (RIO) positions the range marker on the indicator to coincide with the target video. When the range gate marker superimposes the target echo, the ranging circuits place the equipment in the automatic track mode of operation.

The radar ranging function generates a d-c voltage which is proportional to the range of the target being tracked. The radar ranging function consists of the sweep, gate, video, tracking, and on target channels.

RANGE SWEEP FUNCTION.– The range sweep function develops a linear vertical sweep voltage for displaying target range information on the indicator screen and positions this sweep laterally on the screen in accordance with the angular azimuth position of the antenna. The range sweep function contains the range sweep generator and the range sweep azimuth positioning channel.

The start of the range sweep voltage is synchronized with the transmitted pulse by the master trigger from the transmitting function.

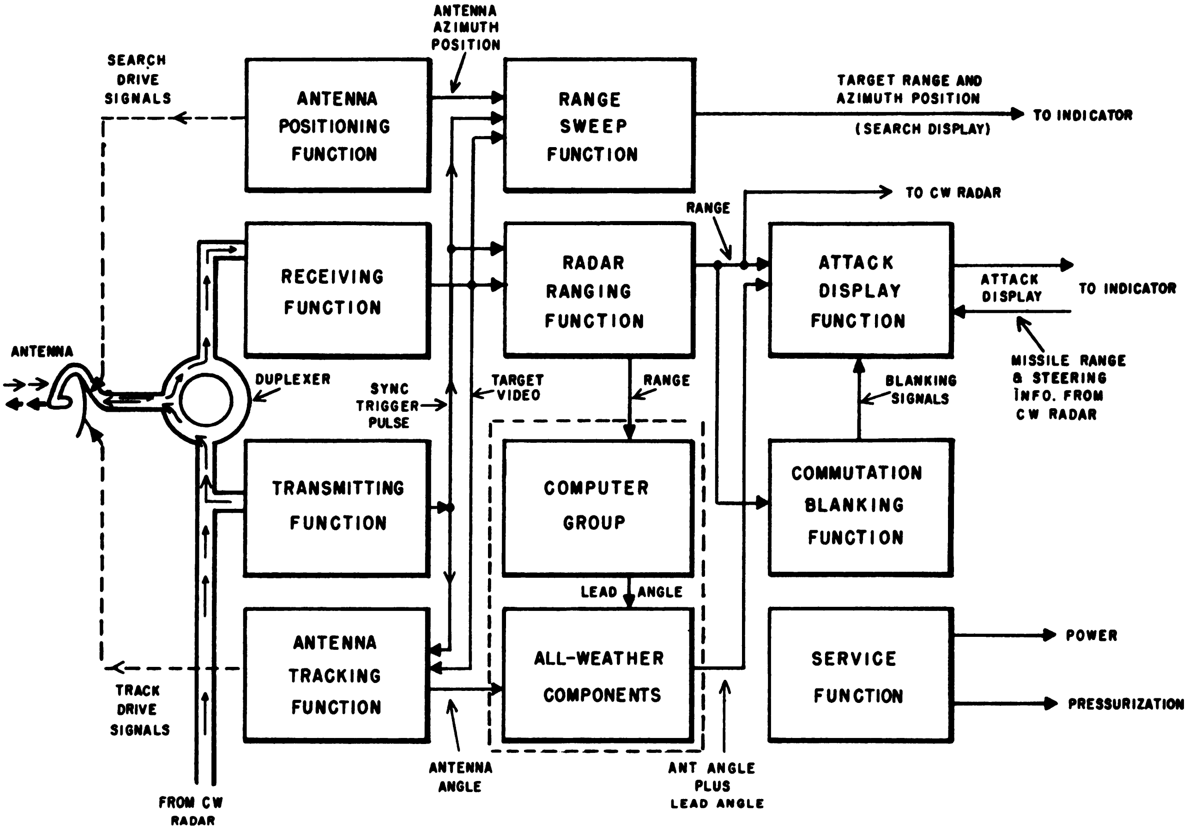

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Figure 14-15. —Functional block analysis of intercept system.

A synchronizing pulse triggers the thyratron modulator in the transmitter, which in turn supplies a trigger to the vertical range sweep.

ANTENNA TRACKING FUNCTION. -The antenna tracking function produces the electrical signals which keep the antenna pointed directly at the selected target during the automatic track mode of operation. This function produces error signals whose phase and magnitude represent angular deviation of the antenna's centerline from the line of sight to the target. The error signal positions the antenna to eliminate the deviation angle. When the antenna is pointed directly at the target, the error signal is zero.

ANTENNA POSITIONING FUNCTION.-The antenna positioning function positions the antenna in azimuth and elevation during the search phase of operation. In the automatic search phase, the antenna positioning function directs the antenna through a selected scan pattern in order to detect targets within the chosen area. In manual search, the antenna is directed by a hand control to point at a selected target or area.

COMMUTATION AND BLANKING FUNCTION. -The commutation and blanking function (fig. 14-15) presents, in rapid sequence, the various elements of the attack display pattern on the indicator. The attack display for guns or rockets consists of the range circle, error circle, error dot, and artificial horizon. Commutation and blanking of the display elements is done by an accurately timed sequential operation of relays. Displays signals are passed by individual relays which are energized for equal portions of the timing cycle. Screen persistence of the cathode-ray/DVST indicator merges the pattern into a composite display.

ATTACK DISPLAY FUNCTION. -The attack display function (fig. 14-15) presents visual information on the indicator. When utilizing rockets or guns, the indicator presentation contains a steering circle and dot; a range circle containing a range rate gap, the angular position of which indicates either increasing or decreasing range rate; B-trace with range markers; and the artificial horizon bar. When utilizing missiles, the indicator presentation contains the aim dot, elevation bar, range circle (range to go to minimum range), B-trace with range markers, and the artificial horizon bar.

SERVICE FUNCTION.-The service function generates and distributes electrical power required for the radar set, and provides pressurized dry air for pressure sensitive units of the system. This system includes the electrical power supply channel and the pressurizing channel.

The electrical power supply section consists of the low voltage power supply and certain distribution circuits. The primary power for

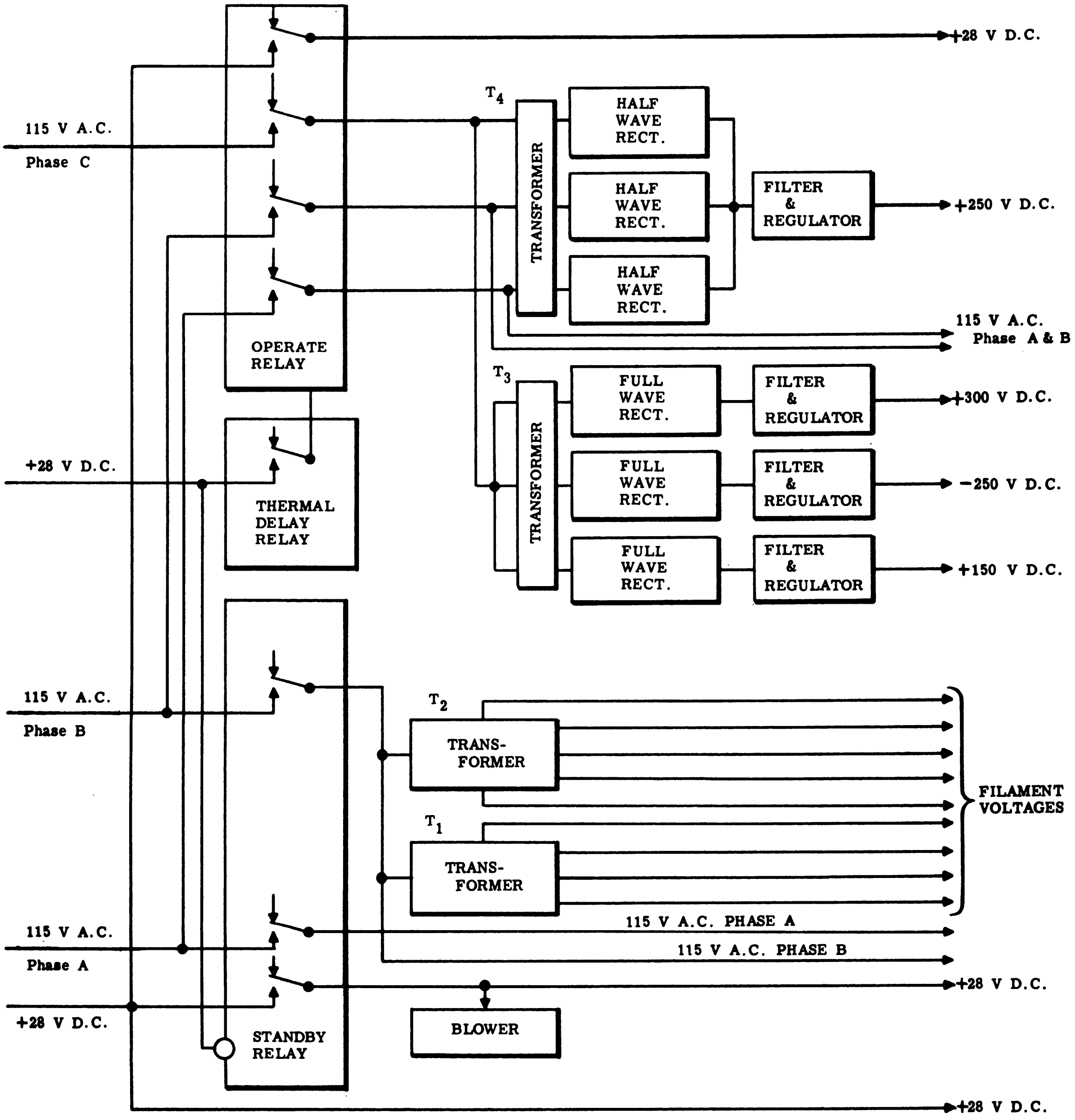

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Figure 14-16. -Block diagram of the power supply system.

the system is obtained from the aircraft 28-volt d. c. and 3-phase, 115-volt, 400 Hz generators. The low voltage power supply provides regulated voltages of 300 v, 150 v, and -250 v for the various units of the system. High voltage is obtained from a voltage quadrupler.

The pressurizing channel automatically maintains for all operating altitudes a dehydrated atmospheric pressure, approximately the same as at sea level, in certain critical units of the radar set. The pressurized dry air prevents arcing of components of the system under conditions of rarefied air or high humidity. Pressurized units are the receiver transmitter and waveguide assembly.

System Analysis

The discussion of the intercept system continues in this section in terms of its functional systems. These systems are the power, transmitting, receiving, range tracking, antenna, computing, and indicating systems. Each system is illustrated in block diagram form with a limited discussion. Where new circuitry is introduced, the discussion is more detailed.

POWER SUPPLY SYSTEM.–The power supply system provides all the operating voltages required by the radar set and the associated equipment. Inputs of 28 volts d. c. and 115 volts a. c., 400 Hz, 3 phase, from the aircraft electrical system are distributed through the power supply system to all units of the radar set. The primary function of the power supply system is to produce the regulated and unregulated d-c voltage outputs required by the system. Figure 14-16 is a block diagram of the power supply system.

When the equipment is in the standby or operate condition, 28-volt d. c. actuates the standby relay. Thus, the filament transformers are energized and filament voltages are applied throughout the equipment. When the power switch is placed in the operate position, the filament voltages are the only outputs until the thermal time delay relay has functioned permitting the operate delay to actuate. Then 28-volt d. c. is available throughout the system and 115-volt a. c. is applied to the rectifier circuits that produce the various B-plus voltages.

Phase C power is applied to transformer T3, which feeds three full-wave rectifiers. The output of each rectifier section is filtered and regulated to positive 300-volt d. c., negative 250-volt d. c., and positive 150-volt d. c. respectively; as shown in figure 14-16.

TRANSMITTING SYSTEM. – The transmitting system illustrated in figure 14-17 consists essentially of the PRF generating circuits (located in the synchronizer), modulating circuits, and a portion of the waveguide assembly. The pulse is generated by a free-running multivibrator which produces the required PRF's.

The PRF generator is a plate coupled free-running multivibrator with a balance control (potentiometer) in the grid circuit to provide alternations of equal duration. The center tap of the balance control is returned to a voltage divider network composed of variable resistors. Each PRF used by the set is controlled by a separate variable resistor and selected as required by relays. Each is independently adjustable with no interaction between them.

The output from the cathode of one side of the PRF generator is transformer-coupled to the PRF driver. The output of the driver is also transformer-coupled to the modulator thyratron which in turn triggers the line discharge thyratron. As a result, the PFN discharges through the pulse transformer, developing the pulse that drives the magnetron.

During rest time, the PFN is charged to a peak voltage of approximately twice the supply voltage through the charging choke and charging diode. The diode cuts off when the resonant peak has passed preventing any discharge of the PFN through the power supply. Any tendency of the PFN to charge in the reverse direction (due to inductance in the circuit) after discharge is prevented by the inverse diode which provides a discharge path to ground.

The despiking network consists essentially of a resistor in series with a capacitor in the PFN to provide filter action, which bypasses the high frequency components in the high voltage pulse. This action lengthens the leading edge of the pulse and opposes any tendency of the magnetron to arc during high power operation. In addition, this network is in parallel with the primary of the pulse transformer, thus providing an impedance match for the PFN until the magnetron fires.

Relay action makes possible the choice of two different pulse widths from the PFN. The output of the PFN is coupled to the pulse transformer where it is stepped up for application to the cathode of the magnetron as a negative pulse. The pulse transformer also produces the radar trigger which is supplied to the indicating system and the range tracking system.

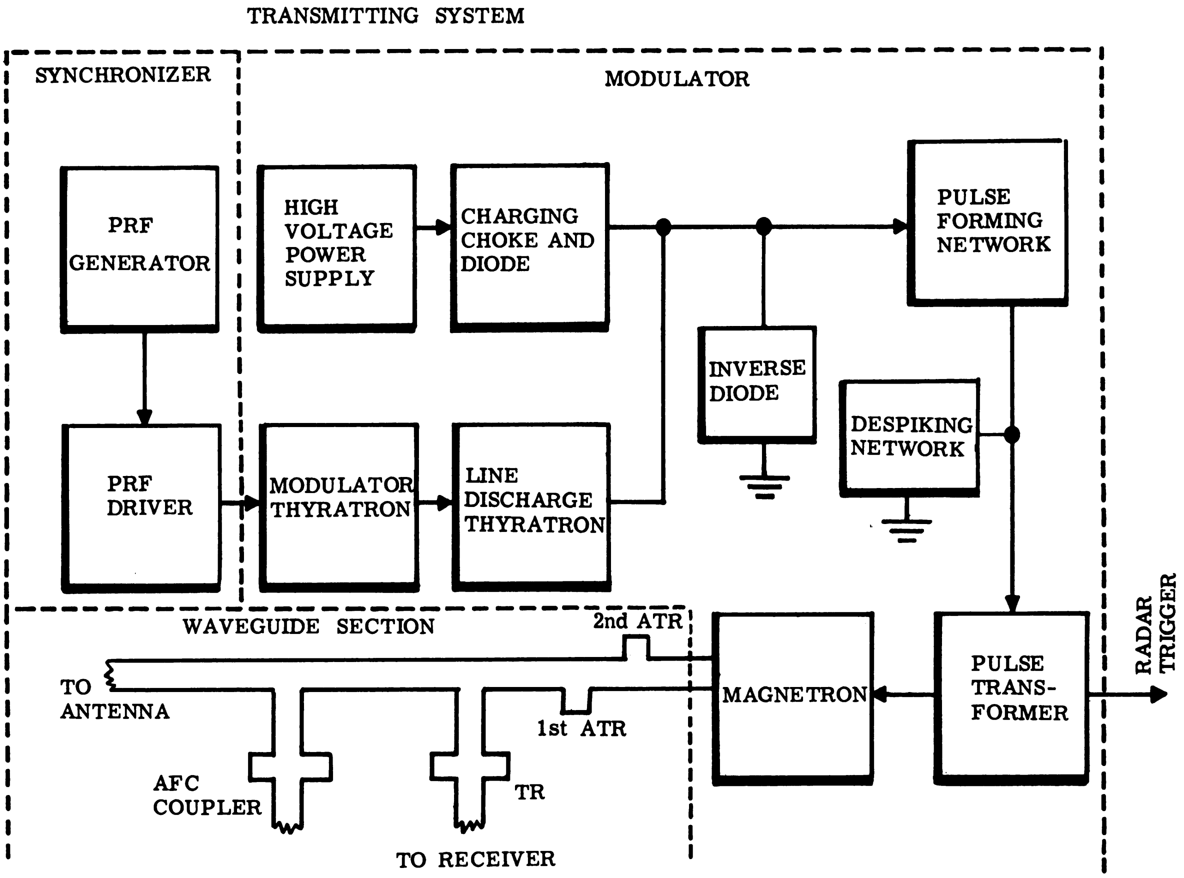

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Figure 14-17.—Block diagram of the transmitting system

When the RF energy from the magnetron enters the waveguide, it ionizes the TR and ATR tubes and passes on to the antenna feed horn where it is radiated into space in a unidirectional pencil-shaped beam. The ionized TR tube protects the receiver during transmit time and the deionized ATR tubes keep the returned energy from being attenuated in the transmitting channel during receive time.

The pulsed RF energy from the waveguide is concentrated and directed by the antenna. The feed horn is offset from the center axis of the reflector and is rotated by the spin motor. This offset focal point causes the energy to be lobed in a pencil-shaped beam about the center axis of the reflector.

RECEIVING SYSTEM. - The receiving system, illustrated by the block diagram in figure 14-18, consists essentially of the antenna and waveguide assembly, IF preamplifier and post-amplifier, video circuits, AFC circuits, and the AGC circuits. The target return is received by the antenna, routed, mixed with the local oscillator's output in the waveguide assembly, and amplified by the IF amplifiers. The IF signal is changed to video, amplified, sent to the indicating system, and the video circuits where it is gated by the range gate from the range tracking system. The gated video is used in the range tracking system. After it is stretched it is applied to the AGC circuits. The AGC circuits produce a negative output voltage proportional to the amplitude of the gated video. The IF amplifiers are provided with manual gain during search and AGC during track operations. The local oscillator's frequency can be controlled manually at the control box or with the voltage from the AFC circuits. Either method changes the repeller

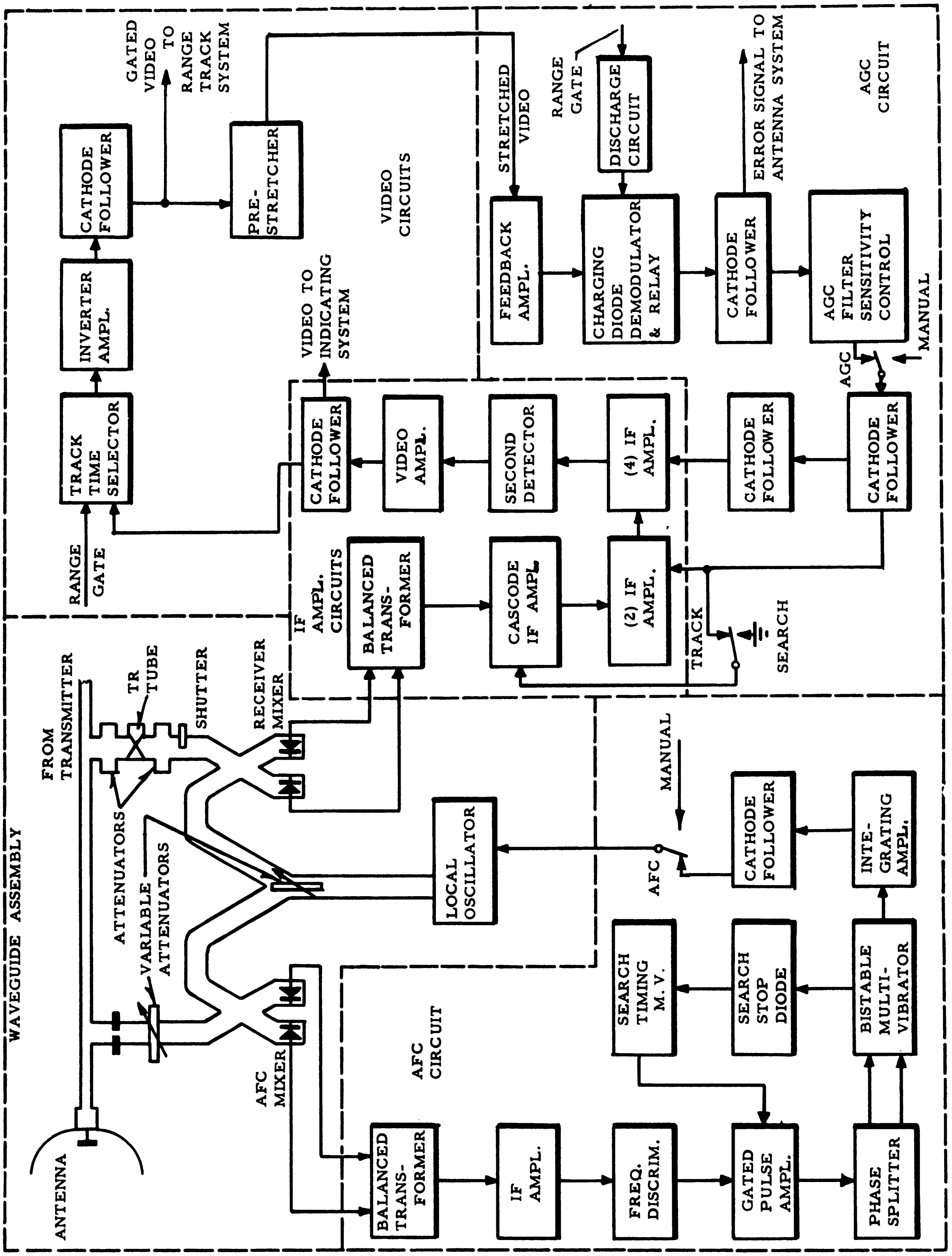

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Figure 14-18.—Block diagram of the receiving system.

plate voltage to keep the IF at the required frequency.

The antenna's parabolic reflector collects and focuses the returned energy from the target into the feed horn. During track operation, the returned signal from the selected target has an amplitude variation which reveals the direction of the target from the centerline of feed horn rotation. From the feed horn the energy passes through rotary joints and flexible waveguides to the receiver portion of the waveguide assembly.

The waveguide assembly in the receiver consists essentially of the AFC and receiver mixers, TR tube, local oscillator, and associated waveguide and attenuators. (See fig. 14-18.) The received signals from the antenna pass through the deenergized TR tube to the receiver hybrid mixer where they are mixed with the local oscillator's output. The mixed inputs are detected by the crystals and applied to the tuned push-pull input of the IF preamplifier. An extremely small fraction of the received signal is coupled through the one-hole coupler to the AFC mixer. However, this does not affect the operation of either mixer.

A small amount of the pulsed energy from the magnetron also passes through the one-hole coupler to the AFC mixer when it is mixed with the output of the local oscillator. The detected output from the crystals is applied push-pull to the balanced-tuned transformer in the AFC circuits. The AFC circuits then produce a change in output voltage to correct whatever error exists in the intermediate frequency.

The frequency of the local oscillator is determined by the adjustment of the cavity and the repeller plate voltage. The repeller plate voltage is supplied by either the AFC circuit or the manual tune control on the radar control box.

The IF amplifier circuit receives the IF signals from the receiver mixer crystals. The signals from the two crystals are 180° out of phase with each other and the local oscillator noise is in phase. The input transformer cancels the noise and reinforces the target signals. This feature greatly increases the signal to noise ratio of the receiver. A filter network on each half of the transformer primary winding provides crystal current to a meter assembly.

The first IF amplifier is a cascode stage consisting of two tubes. The stage is tuned to the IF and provides an excellent signal to noise ratio. During track operation AGC is provided to the stage by a relay.

The next two IF amplifiers are a tuned pair with the first amplifier tuned above and the second below the IF, providing a total bandpass of approximately 5 MHz. Each is cathode biased and both have back bias resistors in the cathode circuits to prevent detuning due to changes in bias. During search operation, the gain of these stages is controlled manually by the operator. AGC is provided during the acquisition and track modes of operation.

The next three IF amplifiers are a triple tuned series and are tuned below, above, and to the IF respectively. The gain of all three stages may be controlled manually or by AGC, depending on the mode of operation. However, the gain control voltage supplied is less than in the previous stages because the gain voltage must pass through an additional cathode follower. (See fig. 14-18.)

The final IF amplifier which is tuned to the intermediate frequency has cathode bias, but does not have AGC or a back-bias resistor. However, during FTC operation a resistor is placed in parallel with the cathode bias resistor to increase the gain of the stage. The output of the stage is transformer-coupled to the second detector.

A filter in the plate circuit of the second detector removes the IF component and passes the video pulses to the video amplifier. When the radar set is put into FTC operation, the coupling time constant is reduced from very long to very short. This action causes large blocks of signals to be broken up, and targets become more distinguishable.

The video signals pass from the video amplifier through a cathode follower to the track time selector in the AGC circuit. However, the ungated video is also supplied to the indicating system.

The automatic gain control voltage is applied to the IF amplifiers as soon as the radar lock-on switch is pressed by the operator. The switch energizes a relay that remains energized if the radar locks on a target and thus provides the AGC voltage. This voltage is negative and varies with the strength of the target signal. The video signal is gated, amplified, stretched, amplified a second time, demodulated, and filtered to produce the AGC output voltage.

The track time selector is a coincidence amplifier. During track, the range gate applied to the grid allows the tube to amplify any video signals present on the suppressor grid. In a sense, the range gate turns the tube on for a fraction of a microsecond and keeps it cut off during the remainder of each receiver listening period. The gated video is inverted, amplified, and sent to a cathode follower. The purpose of the AGC circuit is to maintain the gated video signal output from the cathode follower to the range tracking system at a constant amplitude.

The gated video output of the cathode follower is also supplied to the prestretcher (diode) whose output is supplied to the feedback amplifier. The video at the cathode of the prestretcher causes a charge on a capacitor at the grid of the first stage of the feedback amplifier. When the video pulse is present on the grid of the cathode follower, the capacitor charges through the diode prestretcher and the cathode follower.

After the video pulse has passed, the capacitor discharges through the cathode resistor of the cathode follower and the resistor which is in parallel with the prestretcher. The discharge time is approximately five times the charge time. Figure 14-19 shows the circuitry for the cathode follower, prestretcher, and the input stage of the feedback amplifier.

The stretched video is amplified and inverted in the feedback amplifier. Feedback from the cathode of the last stage in the feedback amplifier to the cathode of the first stage is used to improve the gain stability and linearity of the circuit. Plate to grid feedback in the last stage provides increased gain stability and lower output impedance. Constant gain in the feedback amplifier is necessary to keep the gated video signal input to the range tracking system constant.

The output of the feedback amplifier, a negative stretched video pulse, is applied to the demodulator. The range gate is also applied to the demodulator by way of the discharge (triode) circuit. The output of the demodulator is supplied to a cathode follower from which two outputs are taken.

One output, the angle track error signal, is fed through a capacitor to remove the d-c component and is sent to the antenna servosystem. The antenna beam is lobed in a circular pattern at 50 Hz and if the target is not centered in this conical scan, the strength of the video will vary at that frequency. The phase of this variation is an indication of the direction the antenna should be moved to center the target. The amplitude of this signal indicates the amount of antenna deviation from the center of the beam. The error signal provides this information to the antenna system.

The second output from the cathode follower is passed through a filter that removes the high frequency components from the negative voltage. This output is also limited to prevent it from ever becoming positive. A sensitivity adjustment in the cathode of the limiter insures a zero output for a zero input. The negative d-c output from the filter and sensitivity block is applied by way of a relay to another cathode follower during track operation. The output of this cathode follower is then applied directly to the

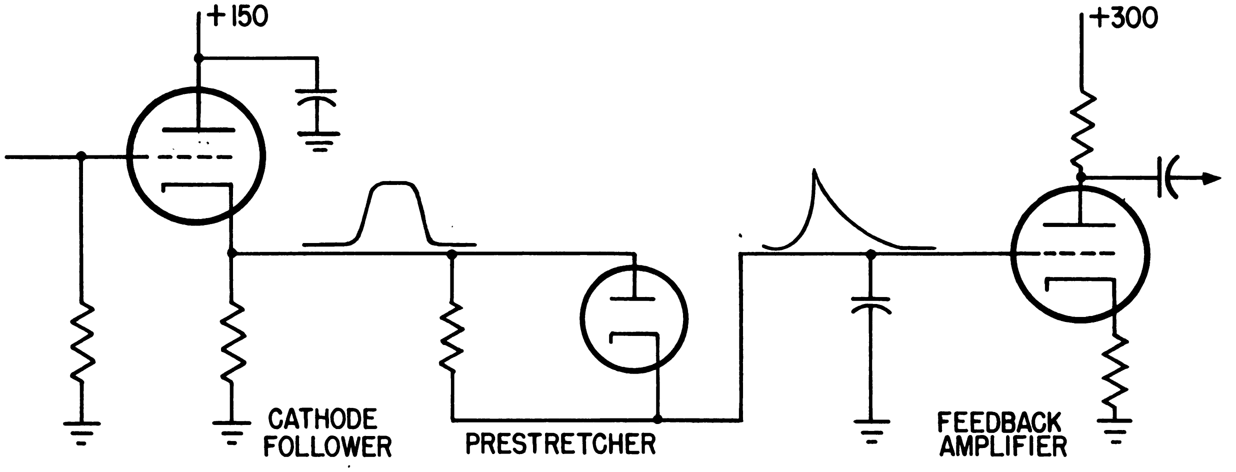

Figure 14-19. –Prestretcher and associated circuitry.

preamplifier section of the IF circuits and through an additional cathode follower to the postamplifier section for automatic gain control.

The automatic frequency control voltage is applied to the local oscillator repeller plate by way of a relay when the tune control on the radar control box is in the AFC position. The AFC voltage has a triangular waveform. When the AFC is searching, the voltage has a large variation ((I) of fig. 14-20) so that the frequency sweep of the local oscillator is sufficient to bring the intermediate frequency within the range of the discriminator. When the AFC is locked on, the amplitude of the voltage variation is small and the local oscillator frequency is kept very close to 30 MHz above the magnetron frequency.

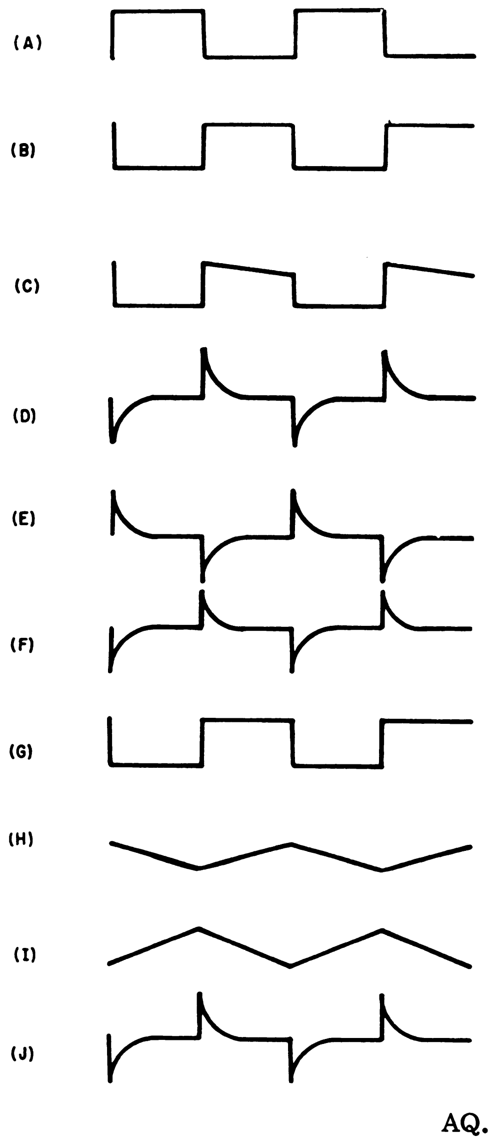

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Figure 14-20.–Waveforms for AFC search.

The AFC search operation begins with the search timing multivibrator, shown in figure 14-18, whose frequency is approximately 1 Hz. A square wave signal ((A) of fig. 14-20) is taken from the plate circuit and applied to the suppressor grid of the pulse gated amplifier. The output from the plate of the amplifier is differentiated and applied to the phase inverter. (See (C) and (D) of fig. 14-20.) The two outputs ((E) and (F) of fig. 14-20) of the phase inverter are supplied through trigger diodes to the bistable multivibrator.

NOTE: The diodes pass only the negative triggers. The bistable multivibrator output is a square wave which is integrated and sent to the integrating amplifier. (See (G) and (H) of fig. 14-20.) The output of the integrating amplifier is applied to the repeller plate of the local oscillator by way of a cathode follower. Here the voltage variation causes the local oscillator frequency to vary until the correct intermediate frequency is reached.

The square wave output of the bistable multivibrator is also differentiated ((G) and (J) of fig. 14-20) and applied to the search stop diode shown in figure 14-18. This input, however, is occurring at such a low rate that it cannot build up much negative charge in the timing multigrid circuit, since it all leaks off between pulses. It is also the wrong phase to trigger. Therefore, it has no effect during AFC search.

When the variation of the local oscillator frequency brings the intermediate frequency close to the required frequency, an output is fed from the AFC crystals to the IF amplifiers. The output of the amplifiers is applied to the discriminator which is tuned to provide a zero output at the intermediate frequency, maximum negative at approximately 2 MHz below the intermediate frequency and maximum positive at approximately 2 MHz above the intermediate frequency. The output of the discriminator is applied to the gated pulse amplifier simultaneously with the gate from the search timing multivibrator. When the gate is positive, pulses from the discriminator pass through the amplifier. When the gate is negative, the gated pulse amplifier is cut off.

The output of the gated pulse amplifier is fed to a phase splitter where the signal is split as shown in (B) and (C) of figure 14-21. For each pulse from the discriminator there will be a negative trigger applied to the bistable multivibrator. (It should be recalled that the trigger tubes pass only the negative triggers.) However, as may be observed in waveform (A), figure 14-21, successive pulses from the discriminator may be of the same polarity. Thus successive negative triggers may be applied to the same tube of the multivibrator. When this situation occurs, the multivibrator is triggered only by the first pulse of the group, and is not triggered again until the discriminator output changes polarity.

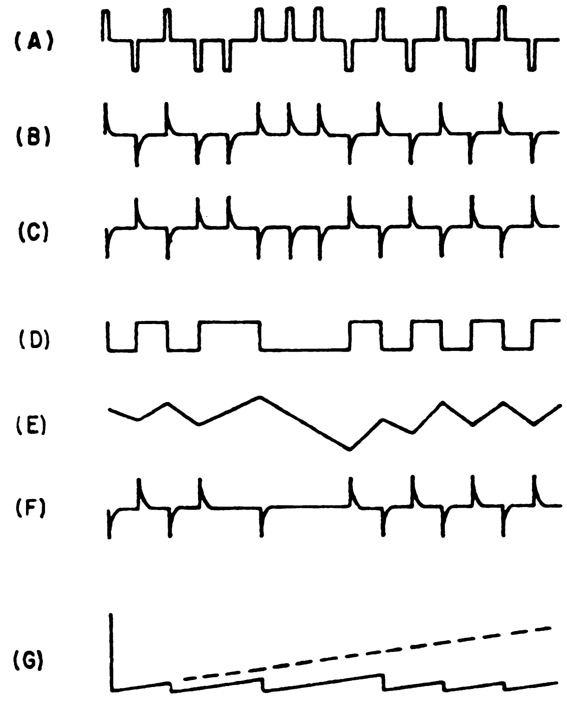

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Figure 14-21.-Waveforms for AFC lock-on.

The output ((D) of fig. 14-21) from the bistable multivibrator is integrated and amplified before it is fed to the cathode follower and to the local oscillator. However, the triangular waveform is no longer regular but varies with the polarity of the pulses from the discriminator. If the local oscillator frequency is too high, the intermediate frequency is also too high and the output from the discriminator is a positive pulse. Referring to figure 14-21, it may be seen that the integrated signal to the amplifier ((E) of fig. 14-21) is negative going when the discriminator output is positive. Hence, the voltage on the repeller plate is becoming less negative and the local oscillator frequency decreases.

If the intermediate frequency is not lowered to the correct frequency by the time of the next transmitted pulse, the discriminator output remains positive, the multivibrator is not triggered, and the intermediate frequency continues to decrease. If the intermediate frequency is driven below the correct frequency, the discriminator output becomes negative, the multivibrator is triggered, the AFC voltage becomes negative going and thus the intermediate frequency starts to increase.

During AFC lock-on, the differentiated output ((D) and (F) of fig. 14-21) from the bistable multivibrator becomes very important. As mentioned previously, when the AFC is searching the negative pulses from the search stop diode have no effect. However, when the discriminator pulses start coming in, the bistable multivibrator is triggered at a much higher rate. Therefore, the negative pulses passed by the search stop diode keep this section of the multivibrator cut off. If the intermediate frequency drifts beyond the range of the discriminator, AFC search begins again.

RANGE TRACKING SYSTEM. -In the process of range tracking, the target is selected by bracketing it between the range strobes on the indicator. During track, the range gate is fixed over the selected target, passing the video that falls within the gate and rejecting all returns from sources at shorter or greater ranges. This gated video is used to correct the range voltage, which in turn selects the position in time of the range gate. The error between the position of the range gate and the target video is the range error, and the range track loop is designed to continuously nullify this error, causing the range gate to track the target motion in range. In addition, the range voltage is sent to the armament control director and indicating system.

During the search phase the range tracking loop is not closed and the position of the tracking gate is dependent upon the setting of the range strobe control. Figure 14-22 is a block diagram of the system during search operation. The sawtooth generating circuits produce a linear sawtooth each time they are triggered. A negative d-c voltage at the range strobe control is the input to the second operational amplifier which produces a positive range voltage output. The comparator produces a positive trigger for each sawtooth input when the sawtooth voltage becomes equal to the range voltage. Thus, the time of this trigger is made proportional to the

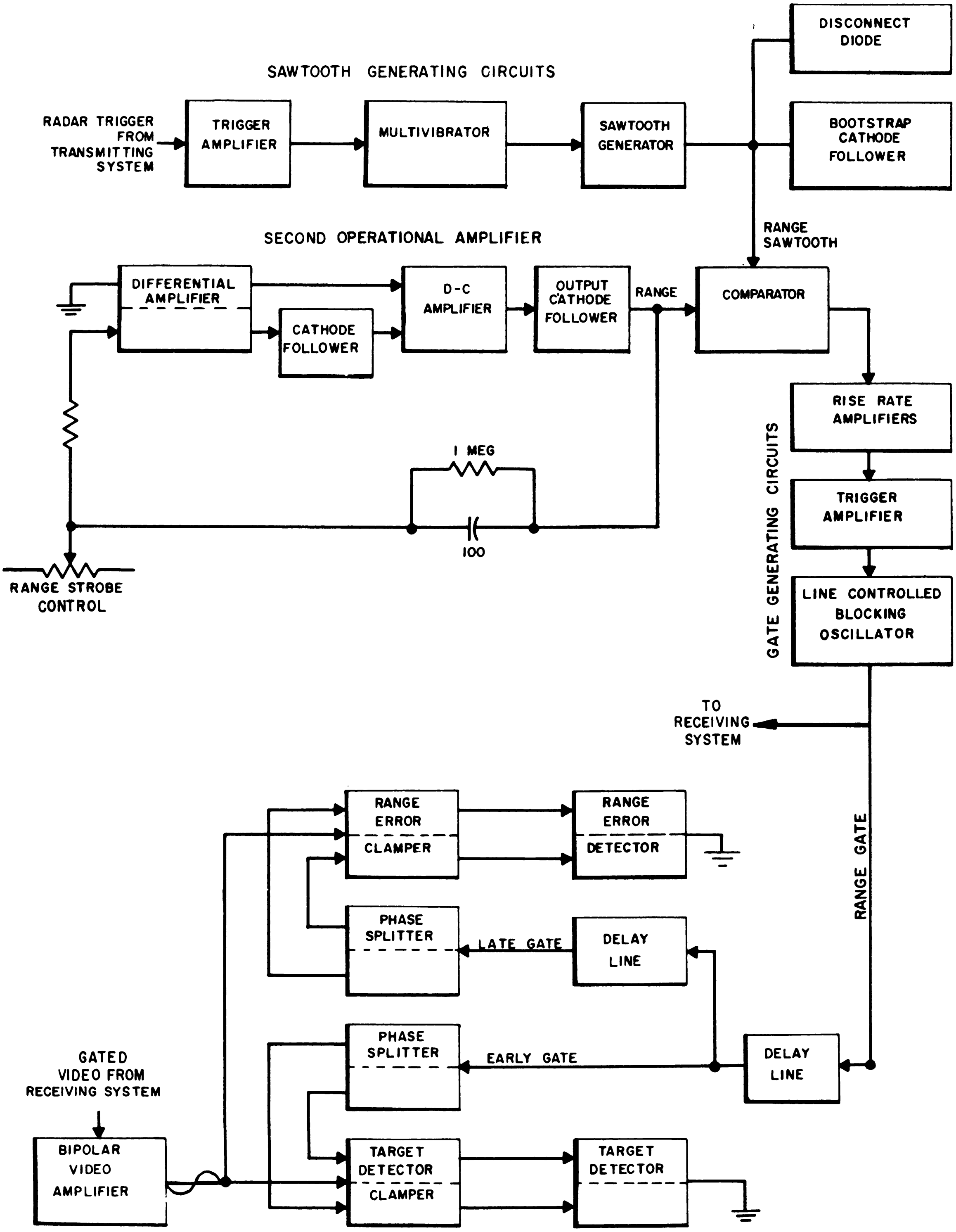

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Figure 14-22.–Block diagram of the range tracking system during search.

range voltage. The triggered gate generating circuits produce a range gate, which is passed through a delay line to produce the early gate and through an additional delay line to produce the late gate.

Gated video from the receiving system is fed to the bipolar video amplifier. The gated video signal is shaped, emerging from the bipolar video amplifier as a bipolar (sine wave) signal. During search, the gated video is very irregular because no one target is bracketed by the range strobes at all times.

The sawtooth generating circuits are shown in block form in figure 14-22. The radar trigger, which is coincident with the firing of the magnetron, allows the normally cutoff trigger amplifier to conduct, triggering the range sweep multivibrator. The negative gate from the multivibrator cuts off the sawtooth generator allowing the range slope capacitor to charge. The disconnect diode and the bootstrap cathode follower causes the slope capacitor to charge at a linear rate.

During search, the input to the second operational amplifier, as shown in figure 14-22, is the range strobe control voltage. The output of the differential amplifier is fed through the other stages to the output cathode follower. Negative feedback to the differential amplifier is provided to insure stability. The range voltage output varies directly with the voltage from the range strobe control.

The range voltage from the second operational amplifier is applied to the cathode of the comparator and the range sweep to the plate. When the sawtooth voltage exceeds the range voltage, the comparator diode conducts and the resulting output is coupled to the rise rate amplifiers and trigger amplifier. When the trigger amplifier conducts, the line controlled blocking oscillator is triggered and produces a pulse which is the range gate. The range gate is passed through two additional delay lines to produce the early and late gates.

As illustrated in figure 14-22, gated video is applied to the bipolar video amplifier from which it is applied to the range and target detector circuits along with the early and late gates. During search, the video signals are irregular because the antenna is scanning and the range error circuits are inoperative; thus, the range tracking loop is not closed.

The acquisition phase is initiated when the range strobes are positioned to bracket the target, the azimuth strobe is placed at the selected target azimuth, and the lock-on switch is pressed, the range strobe sweep multivibrator originates a signal which causes the gates to sweep over a range of 1 mile. If there is a target within this range, the system locks on and the range strobe no longer sweeps. Figure 14-23 is a block diagram of the range tracking system during acquisition and track operation.

The range strobe sweep multivibrator, which was cut off during search operation, begins to free run, and its output alternately energizes and deenergizes the range sweep relay, K1, shown in figure 14-23. When the relay is energized, the inputs to the differential amplifier are the same as during search. When it is deenergized, the range strobe control is grounded and the output of the first operational amplifier is applied to the second operational amplifier by way of the differential amplifier. The feedback network also changes when the relay is deenergized.

The initial output level of the second operational amplifier is determined by the charge on the 2-μf capacitor in the feedback circuit. The other capacitor shown in figure 14-23, which was formerly grounded, begins to charge, providing an increasing positive input to the amplifier. This increasing voltage causes an increase in the range voltage output.

The output change is fed back through the 2-μf capacitor to the differential amplifier and the output resulting from the two inputs is a linearly rising voltage. Thus, the range voltage at the output of the second differential amplifier is proportional to the setting of the range strobe control during one part of the multivibrator cycle, and increases from that value during the other part to provide the 1-mile sweep.

The operation of the sawtooth generating circuits, comparator, gate generating circuits, and the video circuits are the same during acquisition as during search operation. The early and late gates are produced also as they were in the search phase and applied to the range error and target detectors.

When placed in the acquisition phase, the output of the range error detector is applied as an input to the first differential amplifier and ground is also removed from the target detector. Bipolar video from the bipolar video amplifier is applied to both the range error clamper and the target clamper. The late and early gates are also applied to the range error and target clamper respectively.

Only the central portion of the video is passed by the range error clamper to the range

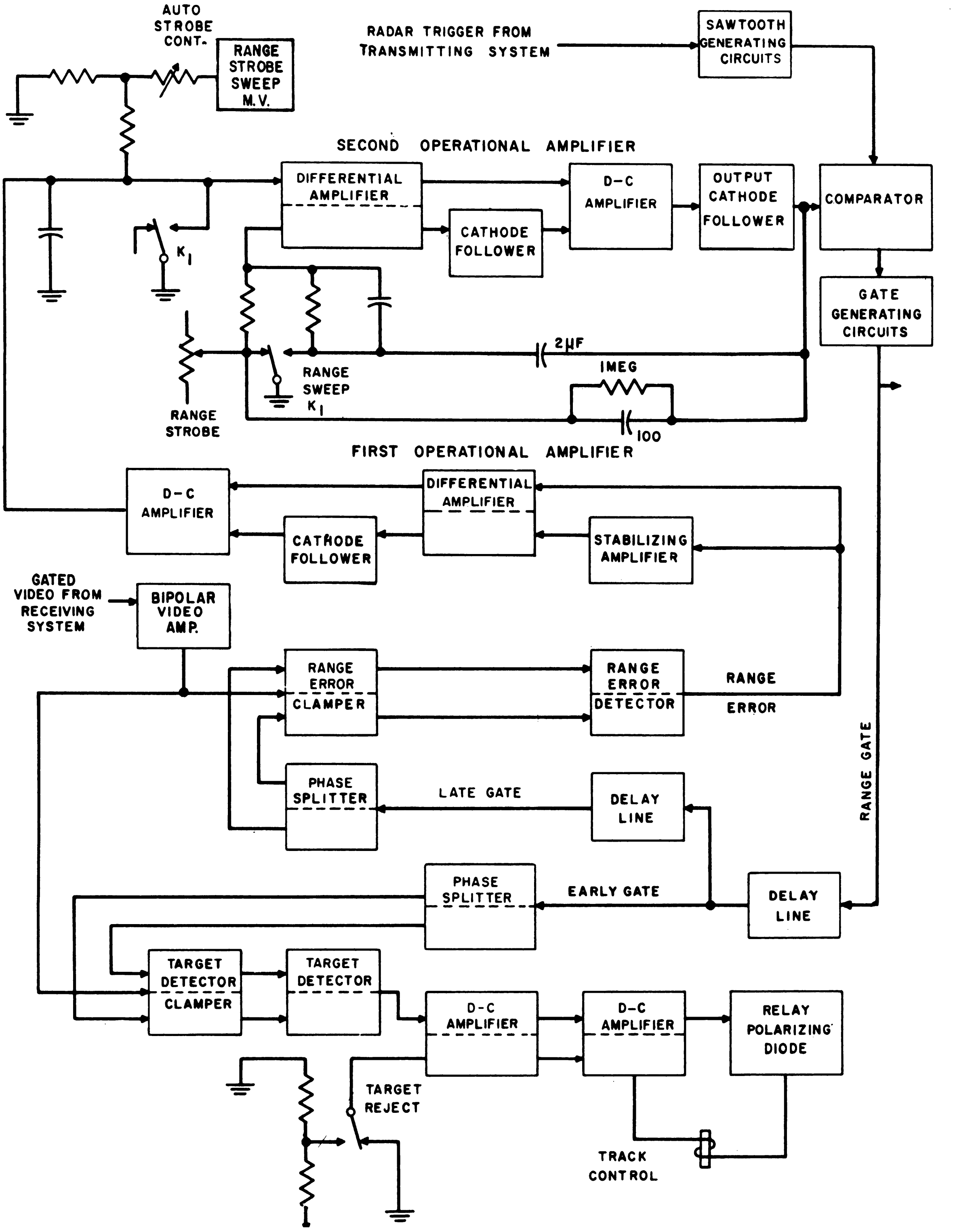

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Figure 14-23. –Block diagram of the range tracking system (acquisition and tracks).

error detector. The output of the detector is proportional to the misalinement of the gate and the video. When no gate is applied both sections of the detector are cut off. When the late gate is centered on the video, the output is zero; if the video is early, the output is positive; if the video is late, the output is negative.

When the range gate passes over a target, and error voltage is obtained from the detector and applied to the first differential amplifier, thus closing the range tracking loop. The output of this amplifier counteracts the increasing voltage at the input to the second differential amplifier and stops the range gate near the target. The positive or negative output from the range error detector coupled through the differential amplifier to the gate generating circuits, repositions the range gate until the late gate lies directly over the bipolar video. In this manner the range circuits can track any variation in target range.

When the range gate is stopped near a target, the negative portion of the bipolar video is passed through the target detector clamper to the target detector which produces a negative signal output. The target detector clampers are cut off by the early gate to pass the negative bipolar video. If negative video is present at the time of the gate, the detector supplies a negative signal to a d-c amplifier. The amplifier produces equal negative and positive outputs which are supplied to another d-c amplifier which controls the current through the track control realy. The polarizing diode shown in figure 14-23 allows the relay to energize only when the output of the detector is negative. When a target bracketed by the range strobes supplies the proper dectector output, the track control relay energizes and places the system in track operation.

During track operation the range error signal represents the difference between the gate position and the target range. The output of the first operational amplifier represents range rate, and the output of the second operational amplifier represents range. During track operation the range tracking system is a closed loop as shown in figure 14-23.

When the target fades, the track control relay will deenergize. Then all search-track relays will deenergize and the system will return to search operation.

ANTENNA SYSTEM.—The antenna system is discussed very briefly in this chapter. A typical antenna servosystem of that type employed in this system is discussed in detail in chapter 8 of Aviation Fire Control Technician 3 & 2. It is recommended that the portion of that chapter pertaining to the antenna system be reviewed before continuing further. Reference to the figure shown in that section should prove beneficial during the following discussion. The portion of chapter 10 in Aviation Fire Control Technician 3 & 2, pertaining to one-plane rate gyros should be reviewed also, since they are applicable to this antenna system. The antenna system functions to supply information representative of target bearing, antenna position, and antenna rate in azimuth and elevation to the various units of the intercept system.

During search operation, the antenna scan pattern is stabilized in azimuth and elevation in order to prevent loss of target due to aircraft climb and roll motion. Regardless of aircraft maneuvers, the antenna scan motion is always parallel to the horizon, and antenna elevation is maintained through climb and dive. Simultaneously, the indicator presentation is stabilized with respect to climb and roll in order to indicate target position relative to the aircraft.

The antenna search servosystem consists of a closed driving loop and an open loop which references the driving loop position voltages to the vertical gyro. Climb and roll signals from the vertical gyro drive the climb and roll servos in the FDU. Servoamplifiers drive motors which position the climb potentiometers, stabilization resolver, roll gravity deflecting resolver, and horizon resolver. (See fig. 14-8.)

It should be noted that the rotors of the reference resolver and followup resolver are clamped to a fixed position to prevent rotation. All resolvers, except the horizon resolver and gravity deflection resolvers, receive excitation voltage from a precesion power supply in the FDU. The stator windings of the stabilization resolver (azimuth and elevation) supply excitation voltage to components in the scan pattern generator and the radar set control, which determine antenna azimuth and elevation command signals. The potentiometer, in parallel with the elevation output of the stabilization resolver, adjusts the stator output voltages with respect to climb, and the resolver determines the phase angle of the output. The azimuth stator of the stabilization resolver is also connected to the indicating system for stabilization of the B presentation.

Azimuth scan signals are produced in the scan pattern generator by a motor driven potentiometer. Elevation jump is produced by alternately short circuiting resistors, and potentiometers control the position of the sector scan. The azimuth and elevation voltages from the scan pattern generator and the FDU are summed and, after amplification, applied to the azimuth and elevation channels respectively. Here the d-c signals are converted to proportional a-c voltages to drive the antenna position motors.

During track operation the antenna system uses the modulation of target amplitude caused by the lobing pattern to generate an error signal. This error signal is received from the AGC circuits in the receiving system and compared by the antenna system phase wise with the azimuth and elevation coordinates of the feed horn rotation. The polarity and magnitude of the resultant d-c voltages indicate the direction of the target and its distance from the center of the lobing pattern. These voltages combined with voltages proportional to the antenna angular rate are used to control the antenna drive motors to center the antenna axis on the target.

COMPUTING SYSTEM.–At this point it is necessary to compute all known quantities to solve for the intercept problem. Since a computer of this type is discussed in detail in Aviation Fire Control Technician 3 and 2, it is considered here only in brief form in order to complete the system.

The tracking radar supplies the director with rate and position signals from the antenna and target range signals from the synchronizer. The FDU, discussed in chapter 10 of Aviation Fire Control Technician 3 and 2, furnishes signals representing true airspeed, air density, and resolved gravity drop. Airstream direction detectors deliver angle of attack and skid signals.

The armament control director (ACD) circuits combine this data in the solution of the firing problem, which is presented on the indicator as steering information for lead collision or lead pursuit during air to air attack mode.

INDICATING SYSTEM.–The indicating system consists of the circuits concerned with the display of information on the CRT indicator. The majority of these circuits are housed in the indicator control unit. A three-gun CRT is used to display the required information to the pilot as shown in table 14-2. Therefore, the indicating system employs three primary circuits–A-gun, B-gun, and C-gun circuits–each of which is discussed. Electronic switching makes it possible to present two indications from the same gun.

Table 14-2. –CRT information displays.

Gun	Search	Track
A	Elevation strobe. Horizon line.	Range rate circle. Horizon line.
B	B sweep.	B sweep.
C	Azimuth strobe	Steering circle. Steering dot.

Since the A-gun circuit presents two items of information on the indicator during each mode of operation, it is evident that a composite blanking signal of the CRT during sweep time will be necessary. The A-gun presentation may be said to be time shared between the horizon line and the elevation strobe or range circle. The elevation strobe or range circle cannot be displayed at the same time as the horizon line or vice versa.

The deflection circuits must also be timed accordingly; that is, the deflection voltages for the elevation strobe or range circle must not be present on the deflection plates of the CRT when the horizon line is being displayed or vice versa. Therefore, two information supplying circuits are required to control the A-gun. One of these, the blanking circuit, is used to control timing; the other, the deflection circuit, is used to provide the deflection voltages. However, both have a common gating and switching circuit which is illustrated in block diagram form in figure 14-24.

It should be noted that the master timing element is a 1-KHz oscillator, whose output is a sinusoidal waveform, (See waveform (a), fig. 14-24 (B).) In addition to being supplied to the deflection and blanking circuits, its output is applied to an amplifier and differentiating network. The network's positive output spikes (waveform (b)) are used to trigger the transient blanking multivibrator during both search and track operation.

The output pulse of the multivibrator is a square wave as shown by waveform (c). It is supplied to the blanking circuit to blank the A gun during the period when the display is changing from the horzion line to the elevation strobe or range circle and vice versa. The transient blanking pulse is also passed through a delay

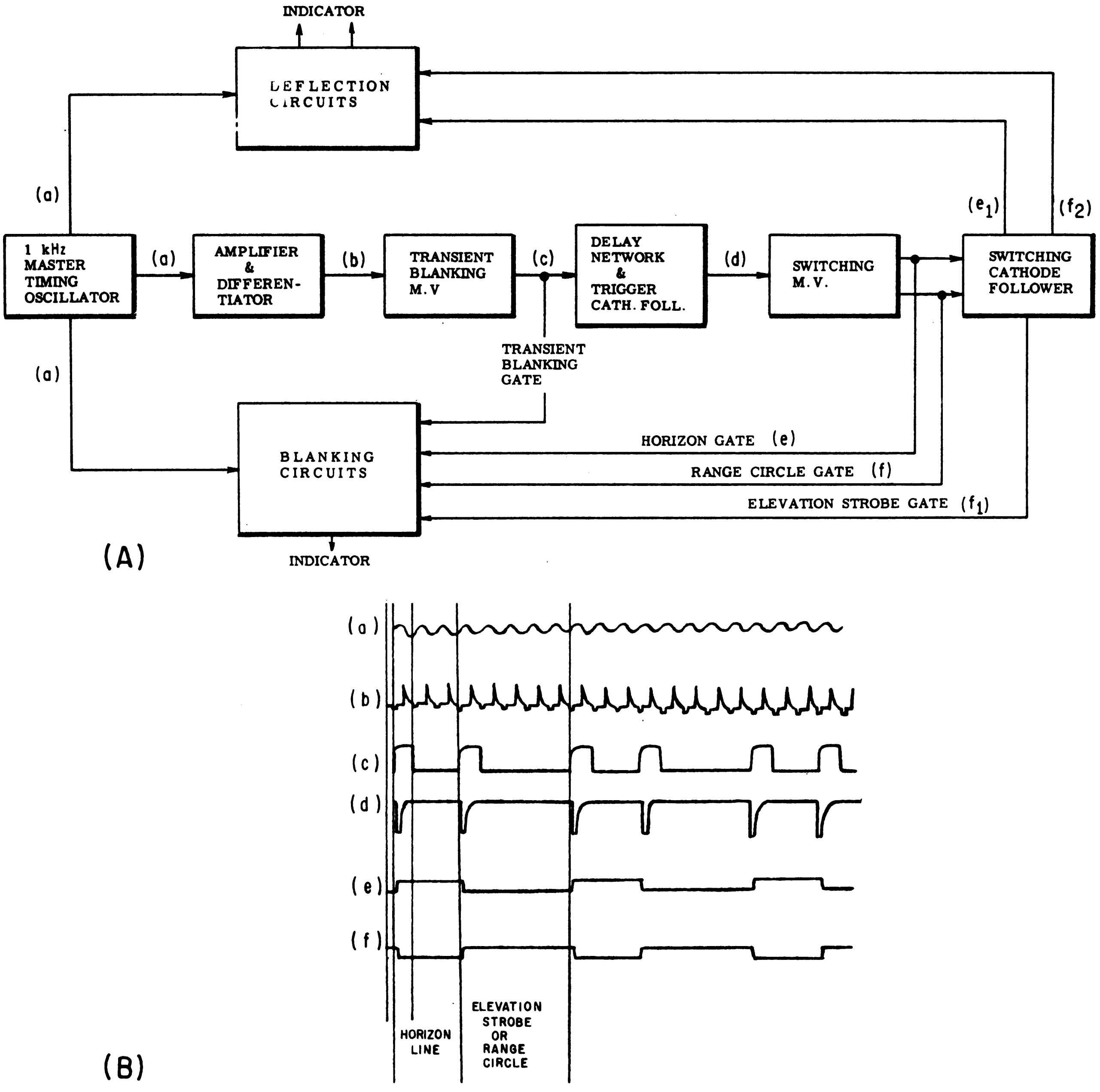

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Figure 14-24. –(A) Block diagram of the A-gun gating and switching circuits; (B) A-gun gating and switching circuit waveforms.

network to a trigger follower, the output waveform (d) of which triggers the switching multivibrator. The short delay permits the transient multivibrator to stabilize before the switching multivibrator is triggered and also insures that the CRT is blanked during the transition between shared displays. The switching gates waveforms (e) and (f) are supplied to the blanking and deflection circuits by way of the switching cathode follower. An additional input to the blanking circuit is supplied from the cathode follower.

The A-gun blanking circuits are discussed in four sections: transient, horizon line,

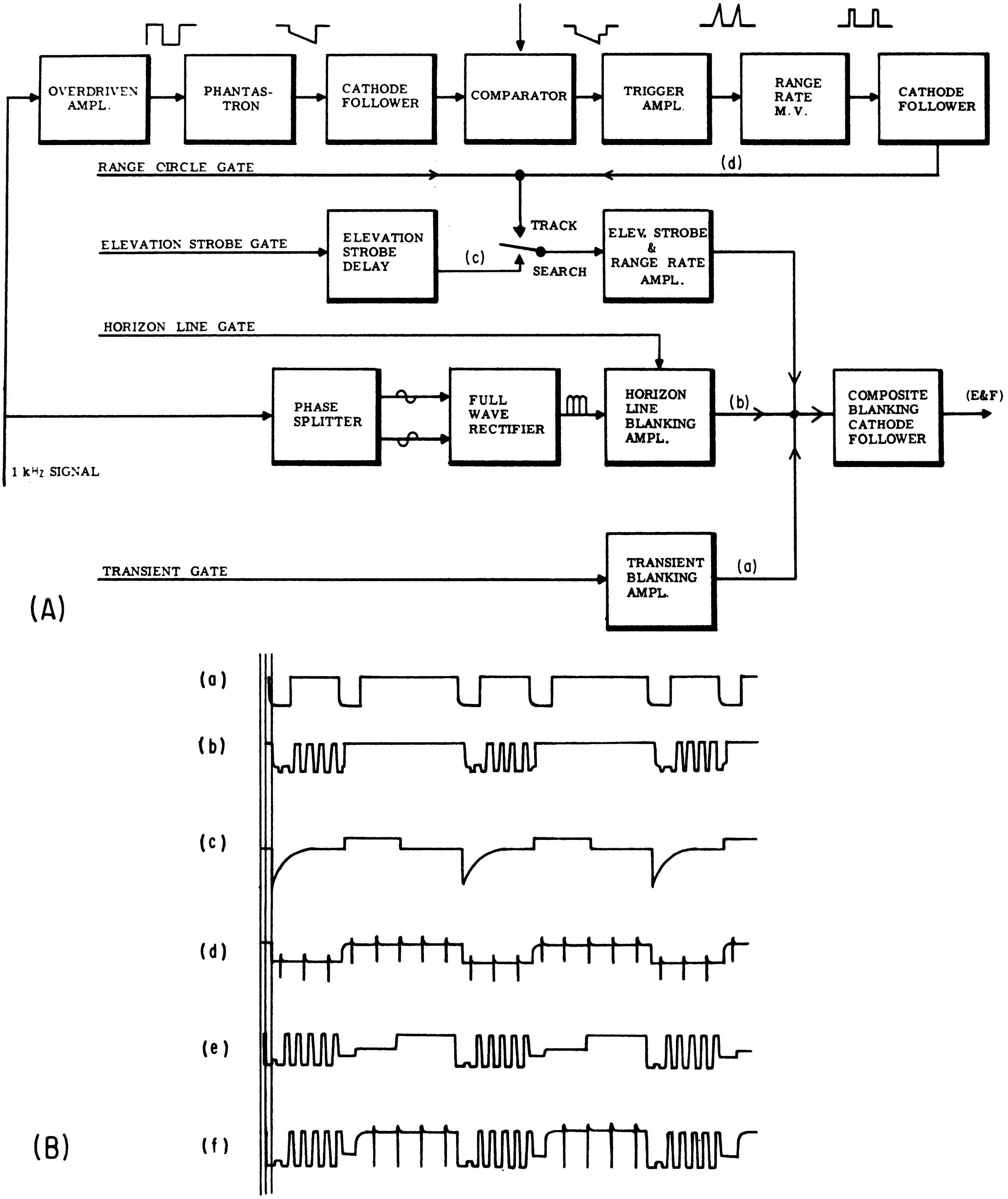

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Figure 14-25. –(A) Block diagram of A-gun blanking circuits; (b) A-gun blanking circuit waveforms.

elevation strobe, and range rate blanking circuits. The transient and horizon line blanking pulses are combined with either the elevation strobe or range rate blanking pulse to produce the composite blanking pulse which is applied to the control grid of the A-gun in the CRT.

The transient gate from the switching circuit is applied to the transient blanking amplifier where it is amplified, inverted, and applied to the composite blanking cathode follower. The circuit and waveforms are shown in figure 14-25.

The horizon line blanking pulse is produced by applying the 1-KHz output from the master timing oscillator to a phase splitter. The two 1-KHz outputs are applied to a full-wave rectifier which produces a 2-KHz pulsating d-c voltage. The output is gated in the horizon line amplifier by the horizon line gate from the switching circuit to produce the horizon line blanking pulse shown in figure 14-25 as waveform (b). This output is then combined with the other blanking pulses to produce the composite blanking pulse.

The elevation strobe gate is applied to the elevation strobe delay. The output of the delay circuit is amplified and inverted and forms part of the composite video during search. (See waveform(c), fig. 14-25 (B).) However, in track operation it should be noted that this output is not used.

During track operation the range rate blanking pulse is used to form the composite blanking pulse. The range rate gap is produced by overdriving the 1-KHz signal (fig. 14-25) and using the leading edge to trigger a phantastron which produces a negative-going sawtooth of voltage. This signal is applied through a cathode follower to a comparator which also receives an input of range rate voltage from the armament control director.

The output is a negative pulse which is a function of range rate. The output is inverted and differentiated by the trigger amplifier and applied as a trigger to the range rate multivibrator. The output of the multivibrator is a very narrow positive pulse which is applied to a cathode follower and mixed with the range circle blanking pulse, thus producing the range rate gap in the range circle. The location of the in the range circle is determined by the time required for the comparator to conduct which is a function of the range rate voltage from the armament control director.

Depending upon whether the equipment is in the search or track mode of operation, either the elevation strobe blanking pulse or the range rate blanking pulse respectively is amplified and inverted, and applied to the composite blanking cathode follower to form the composite blanking pulse. The composite blanking pulses for either search or track operation are shown as waveforms (e) and (f) respectively in figure 14-25.

The A-gun deflection circuits are gated by the gates from the gating and switching circuits previously discussed. They feed deflection voltages to the deflection plates of the A-gun in the CRT. It should be recalled from figure 14-24 that two switching gates 180° out of phase are supplied to the deflection circuits from the switching output cathode follower. One gate is applied to the horizon line amplifiers and the gate to the range circle amplifiers. Thus, when the horizon line amplifiers are conducting, the range circle amplifiers are cut off and vice versa.

(NOTE: Elevation strobe voltages pass through the range circle amplifiers also, but only during search operation.) (See fig. 14-26.)

The horizon line is generated in the horizon resolver in the FDU and results from a combination of three factors—the climb angle of the aircraft, and the sine and cosine of the roll angle. The 1-KHz output of the master timing oscillator is applied to the resolver and demodulator driver, whose output is than applied to the horizon resolver and the horizontal and vertical climb demodulators as a reference voltage. (See fig. 14-26.) The two a-c outputs from the resolver are varied in amplitude by an amount corresponding to the sine and cosine of the roll angle of the aircraft. These signals consist of horizontal and vertical components of the horizon voltage and are applied the two climb potentiometers in terms of cosine and sine of the roll angle, respectively.

The same outputs are also applied to the horizontal and vertical amplifiers, but including a correction for climb angle which is introduced by potentiometers in the FDU. The demodulators supply the bias voltage for the horizon line amplifiers whose outputs are supplied to the deflection amplifiers. The horizon line deflection voltages are combined with the range circle deflection voltages in the deflection amplifiers and then applied to the CRT deflection plates.

The range circle is produced by an output from the 1-KHz oscillator which is fed through the range circle modulator to the horizontal and

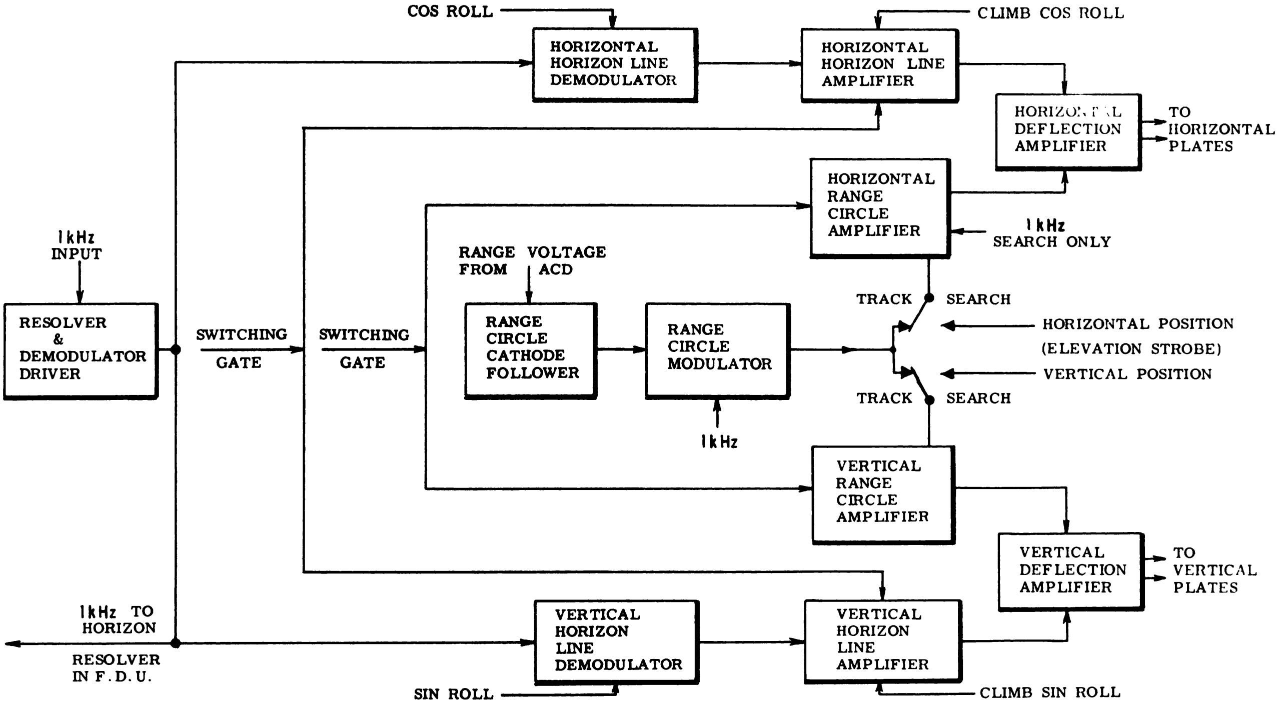
COS ROLL
HORIZONTAL HORIZON LINE DEMODULATOR
CLIMB COS ROLL
HORIZONTAL HORIZON LINE AMPLIFIER
HORIZONTAL DEFLECTION AMPLIFIER
TO HORIZONTAL PLATES
HORIZONTAL RANGE CIRCLE AMPLIFIER
1 kHz SEARCH ONLY
1 kHz INPUT
RESOLVER & DEMODULATOR DRIVER
SWITCHING GATE
SWITCHING GATE
RANGE VOLTAGE FROM ACD
RANGE CIRCLE CATHODE FOLLOWER
RANGE CIRCLE MODULATOR
1 kHz
TRACK
SEARCH
HORIZONTAL POSITION (ELEVATION STROBE)
VERTICAL POSITION
TRACK
SEARCH
VERTICAL RANGE CIRCLE AMPLIFIER
VERTICAL DEFLECTION AMPLIFIER
TO VERTICAL PLATES
1 kHz TO HORIZON RESOLVER IN F.D.U.
VERTICAL HORIZON LINE DEMODULATOR
VERTICAL HORIZON LINE AMPLIFIER
SIN ROLL
CLIMB SIN ROLL

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Figure 14-26. –Block diagram of A-gun deflection circuits.

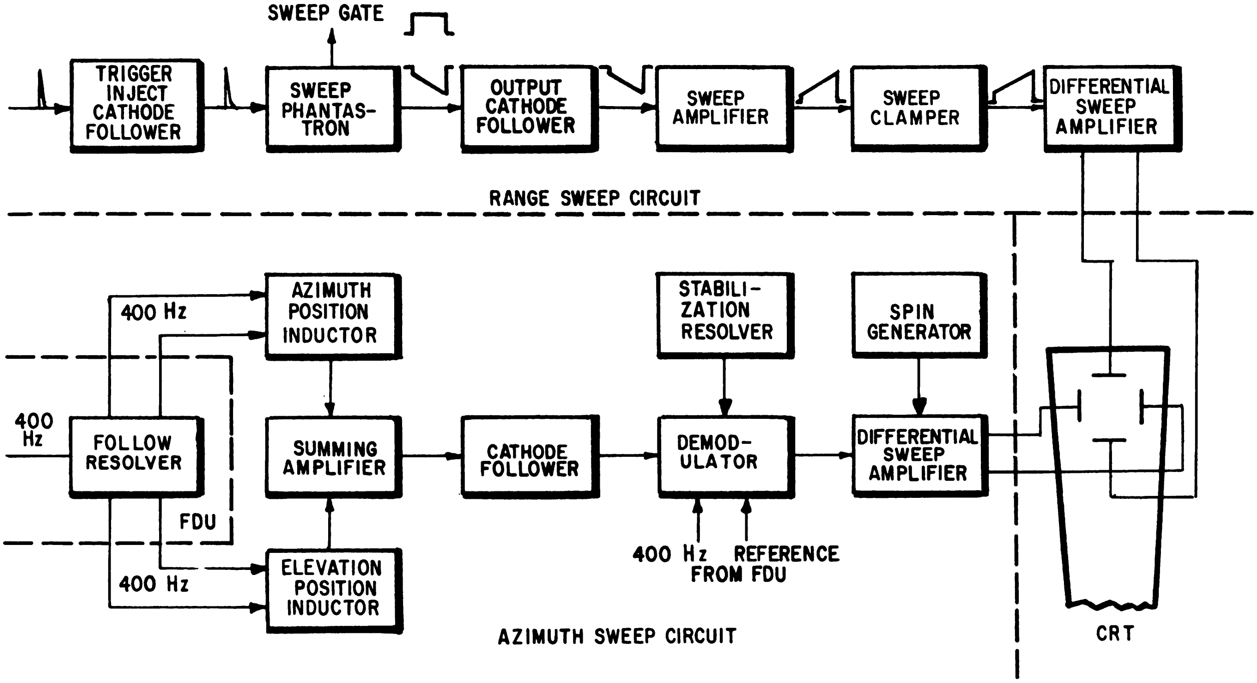

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Figure 14-27. –Block diagram of the range and azimuth sweep circuits.

vertical range circle amplifiers, and then to the deflection amplifiers. The diameter of the range circle is controlled by the range voltage from the armament control director which is applied to the range circle modulator by way of the range circle cathode follower.

The elevation strobe is produced by applying the 1-KHz signal to the horizontal deflection plates during search operation only. The signal is supplied to the horizontal range circle amplifier. The horizontal and vertical position of the strobe is controlled by d-c voltages from the antenna control available to the operator.

The B-gun circuits are discussed in terms of the range sweep (vertical deflection), azimuth sweep (horizontal deflection), and the video circuits.

The range sweep circuit output is applied to the vertical deflection plates associated with the B-gun. A range sweep circuit is discussed in considerable detail in chapter 5 of this manual. Therefore, the following discussion is limited to a block analysis of the range sweep circuit. Figure 14-27 is a block diagram of the circuit.

A positive trigger pulse coincident with the firing of the magnetron is applied to the sweep phantastron through the trigger-inject cathode follower. The output of the sweep phantastron is a negative going sawtooth of voltage. The duration of the sweep is controlled by relays in the grid circuitry of the phantastron which select the proper RC networks to produce sweeps equal in time to various ranges. The range desired is selected by the operator.

The output sweep is passed through the output cathode follower to the sweep amplifier. The negative sweep sawtooth is amplified, inverted, and clamped before being applied to the differential sweep amplifier. The output of the differential amplifier is push-pull and is applied directly to the vertical deflection plates.

The B-gun azimuth sweep circuit is also shown in figure 14-27 by block diagram.

The B-gun azimuth deflection voltages are derived from the output of the followup resolvers in the FDU. It serves to energize the azimuth and elevation position inductors of the antenna with a 400-Hz voltage. The signals from the inductors, which are mixed in the summing amplifier, are indicative of the antenna's position in azimuth and elevation. The output of the summing amplifier is applied to the demodulator by way of a cathode follower. The demodulator compares the input signal with the original 400-Hz reference voltage used to energize the position inductors. The input signal is demodulated and the resulting signals are applied as deflection voltages to the differential sweep amplifier. Its output is a push-pull voltage which is coupled to the horizontal deflection plates of the B-gun.

During roll, the position of the roll resolver is changed mechanically by the motion of the aircraft, thus varying the level at which the demodulator operates. When the wings of the aircraft are not parallel to the horizon, the antenna does not follow a true azimuth scan from the viewpoint of the azimuth position inductor. Therefore, a certain portion of the azimuth deflection signal must be generated in the elevation inductor; both the azimuth and elevation envelopes are mixed at the input to the summing amplifier.

In order to compensate for the apparent variations in target position due to the rotation of the spin motor, the 50-Hz reference voltage from the spin generator is applied to the horizontal deflection plates by way of the differentail sweep amplifier, thus increasing the width of the trace on the indicator.

The B-gun video circuit consists primarily of the following three parts or sections:

1. The range marker generator.
2. The range strobe generator.
3. The video mixer.

The B-gun video circuit must generate range markers and range strobe markers which are mixed with video from the receiving system for application to the control grid of the B-gun. Figure 14-28 is a detailed block diagram of the B-gun video circuits and should be followed as the discussion progresses.

The input to the range marker generating circuit is a positive square wave (gate) from the sweep phantastron which is equal in time duration to the sweep sawtooth. The gate is applied first to an amplifier, which inverts, amplifies, and supplies the signal to a cathode follower. The negative output from the cathode follower is supplied to the range marker gate amplifier and to the mixer circuit as a video pedestal. A positive gate from the gate amplifier is applied to the cathode of the switch diode, cutting it off during sweep time. With the switch diode cut off the range marker multivibrator will free run and generate range marker gates. The output from the multivibrator (the range marker gates) is differentiated and applied to a cathode follower. The differentiated square wave output, a series of negative and positive spikes, is applied to a heavily conducting amplifier. Thus, the positive spikes have

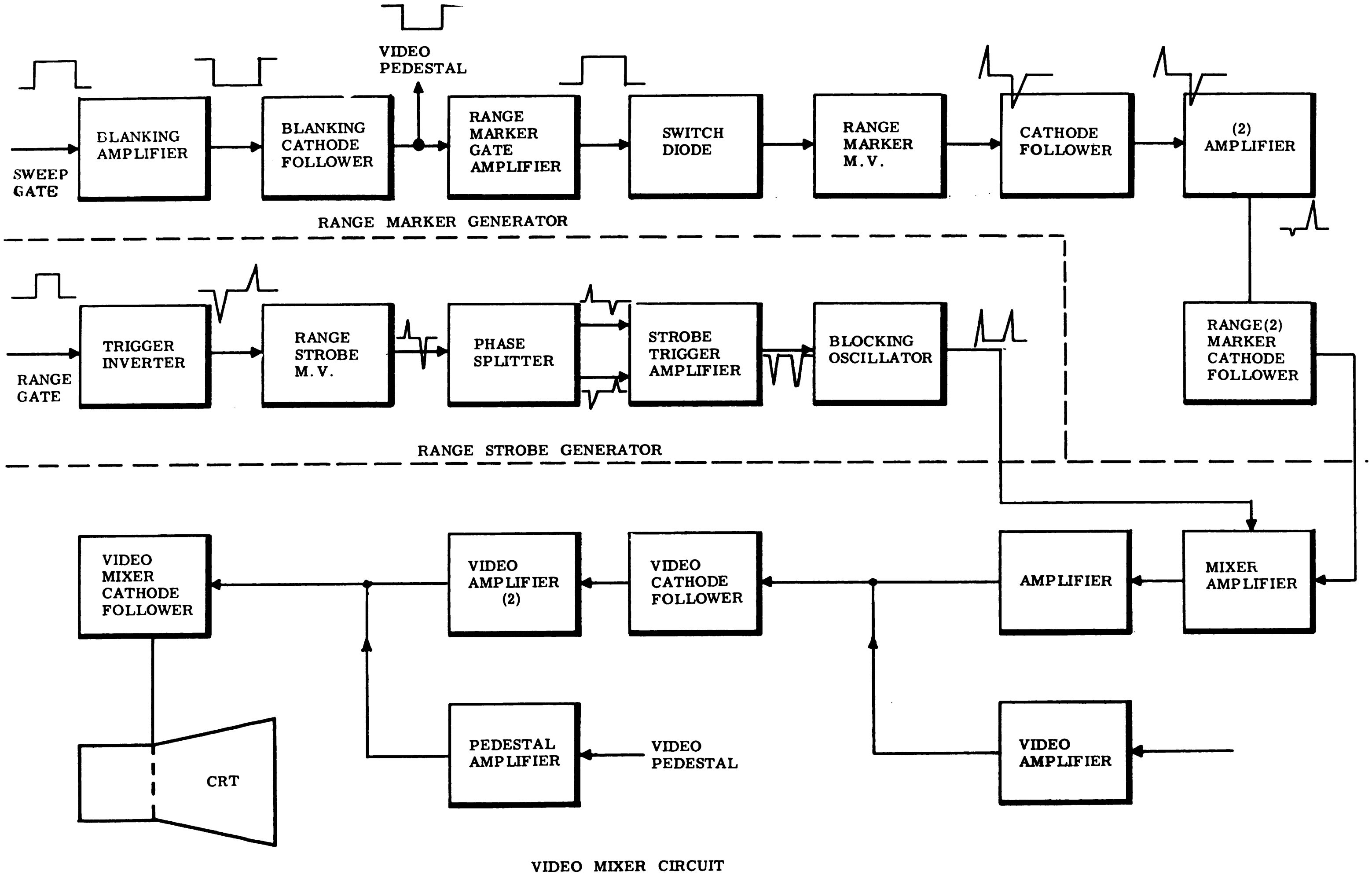

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Figure 14-28. –Detailed block diagram of the B-gun video circuit.

little effect, but the negative spikes are amplified and inverted. The positive spikes are applied to the mixer circuit by way of a cathode follower.

The range strobe generating circuit receives a range gate (trigger) from the range computing system. It is a positive spike which is applied to a trigger inverter. The output, a negative spike, is supplied to the conducting tube of the range strobe multivibrator. The multivibrator produces a square wave with a time duration of 1 radar range mile. The output is differentiated and applied to the control grid of the phase splitter, a paraphase amplifier.

It should be noted that this input is a positive spike followed by a negative spike 12.36 μsec later. One output of the phase splitter will be identical to the input and one will be 180° out of phase with the input. The two output signals are fed to identical amplifiers, both of which are biased at cutoff. Therefore, only the positive spike from each waveform will cause the tubes to conduct. The output from each amplifier is a negative spike and is separated by a time duration of 1 range mile.

The negative spikes are supplied as trigger pulses for another single swing blocking oscillator, the output of which is fed to the mixer amplifier.

The video mixer circuits receive four inputs—range marker, range strobe, video, and video pedestal—all of which are mixed and applied to the control grid of the B-gun. The marker or strobe signals are coupled into the input to the mixer amplifier. The output is further amplified and combined with amplified video from the receiving system. The combined video signals are passed by way of a cathode follower through two stages of amplification after which it is combined with the amplified video pedestal. The composite video is then applied to the control grid of the B-gun by way of a cathode follower.

The C-gun and its associated circuits are provided primarily to present steering circle and dot information on the CRT screen. However, during search operation it does display the azimuth strobe. Figure 14-29 is a block diagram of the C-gun circuits and should be referred to in the following discussion.

During search the signal for producing the azimuth strobe is developed by the 5-kHz oscillator as shown in figure 14-29. The signal is amplified and applied to the vertical deflection plates. However, its vertical position on the screen is determined by a resistive positioning network. The azimuth position of the strobe is determined by voltages from the antenna controller which are applied to the horizontal deflection plates.

During track operation, the vertical and horizontal deflection outputs are used to present and position the steering dot and circle. The steering dot and circle information originates in the ACD. The ACD produces an output voltage which is proportional to the difference between the actual flight path of the aircraft and the optimum flight path for the scoring of hits on a target. These outputs are split into azimuth and elevation circle and dot channels and are applied to their respective amplifiers as shown in figure 14-29.

The signals for producing the circle are generated by the 5-kHz oscillator also and are applied to the cathodes of the horizontal and vertical circle amplifiers. The error signals are applied to the control grids of their respective amplifiers as shown in figure 14-29. The output of the horizontal and vertical circle and dot amplifiers are time shared in the horizontal and vertical deflection amplifiers respectively, the outputs of which are applied in push-pull to the C-gun's deflection plates.

Although the circle and dot error voltages and the 5-kHz oscillator output are continuously fed to the respective amplifiers, the circle and dot must share the presentation time. The alternate display of the circle and dot is made possible by the switching gate multivibrator.

The trigger generator amplifies and differentiates a 400-Hz input to produce the trigger for the switching multivibrator. The multivibrator produces two output gates, 180° out of phase, with one being supplied to the circle amplifiers and the other to the dot amplifiers. Thus, since each amplifier can pass the continuously supplied information only when a positive gate is present on the suppressor grids, the circle and dot are alternately displayed.

The intensity pulse to the control grid of the C-gun is derived from a 400-Hz signal which is amplified by the intensity amplifier. The intensity pulse causes the scope to be unblanked for the duration of the circle and dot display.

CW RADAR SET GROUP

The CW radar set group, utilized with the previously discussed AI type radar missile control system, provides a modulated CW radio frequency signal which, when transmitted by

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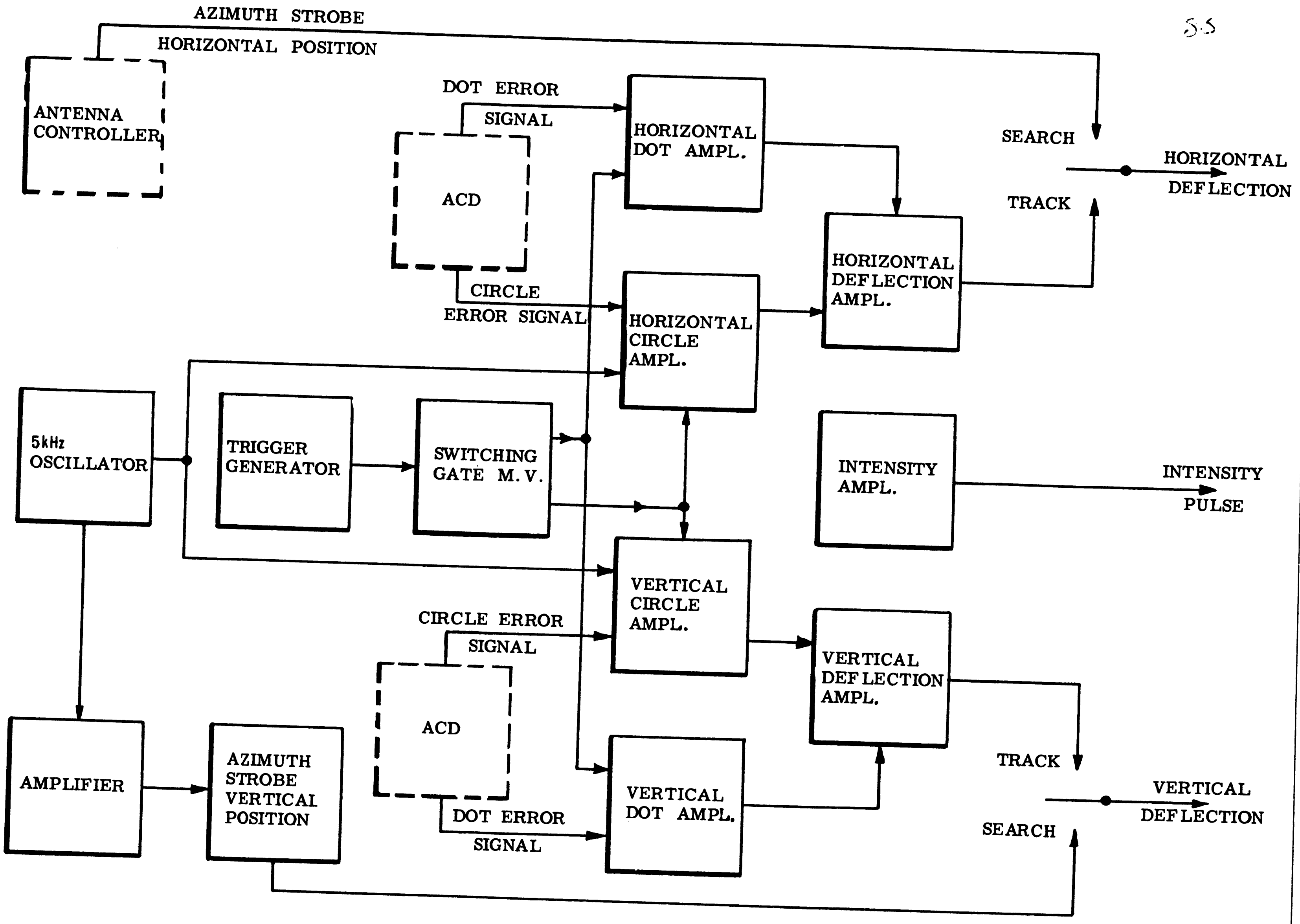

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Figure 14-29.–Block diagram of the C-gun circuits.

the antenna of the AI radar, is used to illuminate an airborne target. This signal, when reflected from the target, is used with the modulated CW-RF signal received directly. These signals are used by the CW radar target seeker in an air to air type missile (semiactive homing) to guide the missile toward interception of the target aircraft. It also provides signals for prelaunch tuning and control of the missile and additional signals which are used by the AI radar to provide the pilot with adequate information to fully utilize the capabilities of the aircraft/missile combination.

The CW radar set group is composed of four major units:

1. Computer-modulator.
2. Power supply.
3. Radar transmitter and cooling system.
4. Flight data computer.

Principles Of Operation

The CW radar set group utilizes these frequencies. The primary, or magnetron frequency, is normally called the "A" frequency. This is the fundamental CW radio-frequency. However, identification of the signal requires coding of the "A" frequency by frequency modulating it with a frequency referred to as "B". The "A" frequency is also frequency modulated by another frequency, for range information to the missile, by a frequency referred to as "C". The frequency "B" coding signal is also amplitude modulated at the frequency "C" rate and is used for range reference in the missile. Thus, the emission from the AI antenna is actually a CW signal which has been frequency modulated by multiple signals. The purpose of these frequencies is explained later in the chapter.

The power output delivered to the AI antenna from the CW radar will determine the missile's normal control range. This range will vary, depending on the condition of the equipment, atmospheric conditions, and aircraft altitude at time of launch.

The normal type AI radar, when used with the CW system, must be modified with a duplexing arrangement which will render the AI radar antenna capable of handling both CW and pulsed signals simultaneously.

The CW radar set group accepts target range information from the AI radar and computes the target's closing velocity. It is used in conjunction with the launching aircraft's true airspeed and altitude data to provide fire control information to the guided missile launching set.

In addition, range data from the AI radar is used by the CW radar set group to produce a simulated Doppler signal that is within the region of the Doppler signal to be received by the missile's target seeker group. The simulated Doppler signal is applied to the missile's speed gate circuits, causing it to lock in the anticipated Doppler frequency region.

Prior to launch (out of range), the CW radar set group transmits pseudo and rear signals to the missile. A portion of the transmitted energy is picked off and fed to the pseudo and rear signal circuits. The pseudo signal is produced by a crystal modulating tee operating as a single sideband generator, mixing two signal inputs from the computer-modulator, with the transmitted energy. The upper sideband output is then coupled to the port and starboard pseudo antenna horns and picked up by the missile. The rear signal is distributed to the rear antenna horns through a magic-T and picked up by the missile's rear receiver. These front and rear signals are compared and effect the tuning of the missile's local oscillator. However, when the pilot closes the master armament switch in the cockpit, the pseudo signal is turned off and the simulated Doppler signal is applied to the missile's speed gate.

The AI radar antenna angle and rates are utilized by the CW radar set group to provide head aim and attitude control voltages for the missile plus lead angle steering signals for use by the AI radar attack display.

Lead angle error signals are used by the lead angle interlock circuit in conjunction with the in-range interlock circuits to prevent firing of the missile when the range is above maximum or below minimum, or lead angle is excessive.

Unit Functions

The basic functions of the CW radar set group and the essential flow of intelligence between major components comprising the missile control system in its missile function are illustrated in figure 14-30. The functions shown are simplified to illustrate the type of information exchanged within the missile control system and do not represent the actual circuit connections. Figure 14-31 should be referred to for the following discussion on the CW radar units' functions.

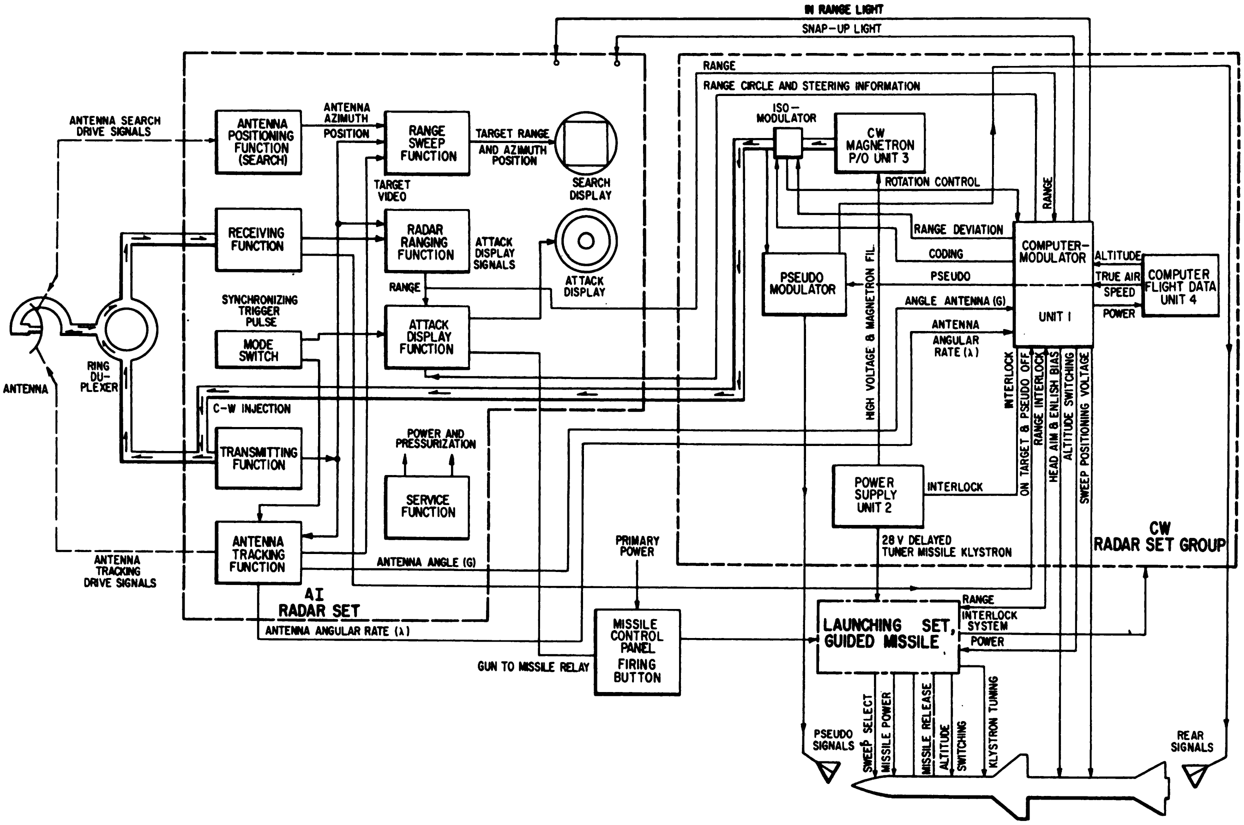

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Figure 14-30.–Functional block diagram of a typical Airborne Missile Control System.

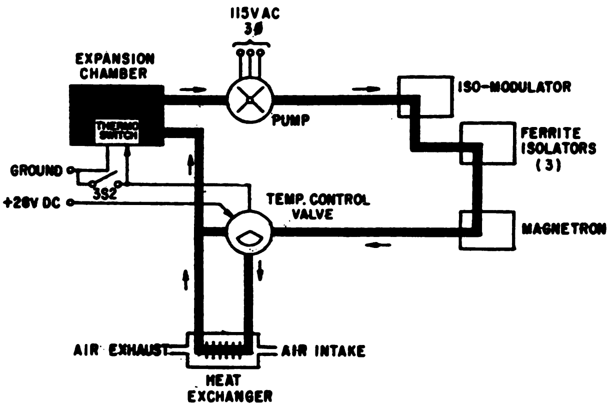

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Figure 14-31.–Magnetron cooling system, functional block diagram.

COMPUTER-MODULATOR.–The computer assembly (lower half of the computer-modulator, unit 1) performs the following functions:

1. Receives and processes target range signals from the AI radar and true airspeed and altitude pressure signals from the flight data computer (unit 4); and furnishes a range interlock to the launching set indicating when a specific target is within range of the missile. These signals are also processed to provide firing range to go, and maximum range information for use by the AI radar.

2. Receives target range and azimuth and elevation rates from the antenna; and furnishes the missile head-aim and attitude control (English-bias) voltages and lead angle steering information (aim-dot) to the AI radar display. The head aim output signal is a summation of antenna rate and position plus range applied to the missile's head control circuits to slave the missile's front antenna with the AI radar's antenna at launch. The English-bias output is also

a summation of antenna rate and position plus range applied to the missile's flight control circuits to actuate control surfaces in establishing the proper missile collision attitude. The aim-dot output is fed to the AI radar indicator as the summation of antenna rate and position plus range, providing a lead pursuit course steering aid in the form of a dot on the attack display.

3. Receives and processes altitude pressure data from the flight data computer for use by the missile's autopilot gain control circuit. Thus, with a given angular error, the magnitude of the steering signals applied to the control surface servosystem is a function of the altitude of the missile at launching.

4. Processes the target signal range to provide a simulated Doppler signal which corresponds to the expected signal of the specific target. The simulated Doppler output signal is fed to the missile and locks the missile's speed gate in the region of the target Doppler.

The modulator assembly of the computer-modulator performs the following functions:

1. Supplies the voltage used by a ferrite isomodulator to frequency modulate the CW magnetron/klystron at a frequency "C" rate so as to provide range information to the missile.

2. Provides the voltage used by a ferrite isomodulator to frequency modulate the CW magnetron/klystron at a frequency "B" rate so as to provide coding used to identify the illuminating source to the missile.

3. Amplitude modulates the frequency "B" coding signal at a frequency "C" rate to provide range reference for the CW target seeker of the missile.

4. Provides a frequency-modulated voltage (frequency "C" deviation) to be used to provide artificial target closing velocity and range information (pseudo signal) to effect the tuning of the missile's local oscillators, and to indicate proper missile target seeker operation prior to launch.

5. Accepts and processes information at the ranging frequency from the isomodulator (P/O Unit 3) to effect bias rotation control of the isomodulator. An interlock is included for protection of the CW magnetron/klystron in the event of failure of the bias rotation voltage supply.

HIGH-VOLTAGE POWER SUPPLY.—The power supply provides the filament and high voltage source for the magnetron/klystron. It contains a cam operated time delay circuit for proper operation of the system. This time delay circuit controls the application of the filament voltage to the magnetron/klystron and 28-v d. c. (delayed) to the klystron tuners located in the missile pylons.

The unit is mounted in a pressurized shock-mounted case to allow operation at high altitudes. Cooling is accomplished by means of ram air forced through a plenum chamber where grooves in a cold plate deck aid in extracting heat. Two ports on the case provide air intake and exhaust for the plenum chamber.

RADAR TRANSMITTER.—The radar transmitter consists of a magnetron/klystron assembly (newer systems utilize a multicavity klystron vice a magnetron), three CW isolators, two additional waveguide couplers, a filter-T assembly, a pseudo modulating T, two magic-T's, two pseudo signal horns, two rear signal horns, and the magnetron cooling system. The radar transmitter performs the following functions:

1. Generates the CW-RF carrier signal.

2. Frequency modulates the CW-RF carrier at a frequency "B" which is the coding signal used to identify the illuminating source to the missile.

3. Frequency modulates the CW-RF output signal with a frequency "C" signal for use by the CW radar target seeker of a missile for range reference.

4. Provides suitable coupling, filtering, and isolation for the CW and pulse RF signals.

5. Single sideband modulates an RF carrier signal with a pseudo Doppler frequency.

6. Distributes and radiates a portion of the FM-CW carrier signal by means of the two rear signal horns.

7. Distributes and radiates the modulated pseudo signal by means of the two pseudo signal horns.

The magnetron assembly is the RF power source of the radar transmitter. It is comprised of a CW magnetron/klystron, an isomodulator with a crystal detector, and associated plumbing.

The microwave power source for CW illumination is a high power type magnetron/klystron operating at "A" frequency. If a target were illuminated with pure CW energy alone, the reflected energy would provide only target speed, target direction, and warhead detonation information to the missile during flight. In order to provide other necessary information to the missile, the transmitted energy is frequency modulated.

This is accomplished through the use of an isomodulator located at the output of the magnetron/klystron. The isomodulator is a ferrite device which is capable of rotating the plane of polarization of its microwave input. Two coils in this device receive "B" frequency and "C" frequency modulating signals from the computer-modulator. The input and output connecting waveguide portions of the isomodulator differ in polarization and, in the absence of modulating signals in the two coils, all of the CW energy is allowed to pass through. When the rotating plane of polarization is caused to depart slightly by the modulating signals, the output polarization is no longer correct for complete transmission. Consequently, a controlled mismatch is created at the output flange of the isomodulator. A portion of the microwave energy is reflected back through the isomodulator input guide to the magnetron/klystron and the isomodulator location is such that this reflected energy pulls the magnetron/klystron at the two modulation frequencies.

The "B" frequency signal which frequency modulated the "A" frequency signal is used for coding. This coding frequency is detected in the missile at the output of the rear IF amplifier and is used to identify the missile with the illuminator of its own launching aircraft.

The "B" frequency is amplitude modulated at "C" frequency providing range reference to the missile.

A "C" frequency signal frequency modulates the "A" frequency signal to provide range information to the missile. The "C" frequency FM is reflected from the target and is received by the missile's front antenna. The "C" frequency signal is extracted and compared with the range reference to detect a phase difference proportional to target range. This intelligence is used by the range arming circuit of the missile.

The CW injection plumbing, consisting of the waveguide and associated detail parts required to inject high power microwave energy into the antenna of the AI pulse radar, is located in the nose section of the aircraft and performs the following functions:

1. Directs microwave energy from the CW magnetron/klystron to the antenna of the AI radar.
2. Prevents CW energy from entering the receiver of the pulse radar and, in turn, prevent pulse energy from affecting the CW magnetron/klystron.
3. Prevents antenna search and scan variations from pulling the CW magnetron/klystron away from its nominal frequency.
4. Provides couplers for picking off energy for the rear and pseudo signal horns.

The CW magnetron/klystron is isolated from target reflections which return in the same plane of polarization as the energy being transmitted. The reflected energy, if allowed to enter the output arm of the waveguide, would cause the magnetron/klystron to be pulled off frequency. Three isolators, therefore, are used in the output arm of the waveguide to provide the necessary isolation. The isolator is a ferrite device which is also capable of rotating the plane of polarization of microwave energy passing through it. The ferrite in the isolator is nonreciprocal; i.e., the plane of polarization of energy passing back through the ferrite is rotated in the same direction as the energy being transmitted.

The output waveguide of each isolator is rotated with respect to its input waveguide to allow complete transmission of the energy entering the isolator. Positioning of the input guide of each isolator in the series is automatically governed by the plane of polarization of the energy leaving the preceding isolator (or isomodulator in the case of the isolator in the series). Consequently, the vertically polarized energy which enters the isomodulator is rotated through the action of the isomodulator and the three isolators and is transmitted in the vertical plane of polarization.

Energy reflected from the target is in the correct plane of polarization to enter the transmission line. However, as the energy passes through the isolator, the ferrite rotates it, thereby causing it to be at right angles to the isolator input guide. In this way, the unwanted energy rejected through the nonreciprocal action of the ferrite in each of the three isolators is dissipated in the side arm. A side arm load is located at the input guide in the correct plane to dissipate the unwanted energy.

The magnetron/klystron cooling system is a closed system which dissipates excessive heat from the magnetron and associated ferrite parts. Figure 14-31 is a functional block diagram of the cooling system. It consists of an expansion chamber, pump, temperature control valve, and a heat exchanger. The system uses OS-45 as a liquid coolant.

When system power is applied, the cooling system receives input power to the pump and to a thermoswitch in the expansion chamber.

The pump operates continuously, circulating the coolant. The temperature control valve is a three-way valve which controls the return of the coolant to the expansion chamber. If the coolant has been heated to a temperature of 60° F by magnetron/klystron, the thermoswitch closes, applying 28-v d. c. to the control valve This voltage energizes a solenoid within the valve which, in turn, opens the valve outlet to the heat exchanger. The heated coolant passes through the heat exchanger, where it is cooled, and returns to the expansion chamber. The heat exchanger is supplied with ram air which absorbs the dissipated heat of the coolant.

When the coolant falls below 60° F the thermoswitch opens, causing the control valve solenoid to deenergize. The valve will then direct the coolant back to the expansion chamber, bypassing the heat exchanger.

Switch 3S2 bypasses the thermoswitch, when closed, for testing and oil filling purposes.

FLIGHT DATA COMPUTER.—The flight data computer, measures true airspeed by means of a barometric pressure assembly. The two assemblies deliver true airspeed and altitude data to the computer-modulator.

In the newer systems, the flight data computer is not a component part of the system, although inputs of airspeed and altitude are still recieved from it and used in its computations.

MAINTENANCE

Generally, maintenance procedures are designed to be performed on the equipment in the aircraft to reduce aircraft downtime. However, the procedures are also applicable for use on an operating test bench setup. Every effort is made to reduce the test equipment requirements and to simplify the test and alinement procedures without sacrificing accuracy.

GENERAL PRECAUTIONS

Certain general precautions should be observed when equipment is first energized after maintenance or service work has been performed. Even though specific warnings and cautions are included at appropriate places in directions, the general precautions listed here should be kept in mind. While the equipment is installed in the aircraft, it should be turned on periodically, as dictated by local operational and environmental conditions, as a precaution against moisture. After repair or replacement of any component or subassembly of the system, and prior to any electrical test, the following checks should be made on all components involved:

1. See that the correct plug-in parts such as tubes, molded units, and relays, are in place.
2. Make correct and complete mechanical and electrical engagement of all chassis connectors such as synchro plugs, tube caps, and servomotor plugs.
3. Make sure of complete electrical and mechanical engagement of all subchassis.
4. Check for proper and free mechanical action of movable assemblies and controls.
5. After any servicing in which the indicator or modulator covers have been removed or the waveguide dissembled, repressurize and check for air leaks after replacement.

SCHEDULED MAINTENANCE

The requirements and demands placed on the aircraft maintenance organization for support of the Navy's modern weapon systems have increased substantially. Many separate but interrelated functions and tasks combine to make up the maintenance workload that is required for support of our present day aircraft. The time allocated and avialable for the accomplishment of this maintenance does not allow for all of these tasks to be considered, planned, and performed on an individual basis. It is necessary that they be combined and sequenced in the proper order if the overall job is to be accomplished in the most efficient manner and within the allocated time. The best possible use of allocated time, manpower, materials, and funds is mandatory if the maximum potential weapon system availability and utilization is to be realized.

The maintenance requirements prescribed as periodic maintenance requirements are the minimum necessary under any conditions to assure timely discovery and correction of latent defects. Compliance is mandatory. Also, the designated calendar intervals are the maximum authorized based on aircraft class and planned service-wide utilization. Due to varying operational requirements, climatic, or environmental conditions, cognizant commanders may increase the scope or frequency of material inspection or examination as required to properly and safely support operations.

Periodic Maintenance Requirements Manual (PMRM)

The PMRM contains the minimum scheduled maintenance requirements directed toward the weapon system. The information in the PMRM is presented in a manner readily usable by maintenance personnel in planning workloads and researching requirements for the weapon system. The manual contains general instructions, preventive tasks, component removal/ replacement schedules, accesory record card requirements, and the functional test flight requirements peculiar to the weapon system.

Maintenance Requirements Cards (MRC's)

The maintenance requirements are published on 5- x 8-inch cards in order to provide the maintenance man a ready reference to perform the scheduled maintenance on the weapon system. Each MRC contains one or more detailed maintenance requirement. Illustrations, clearances, tolerances, charts, and part numbers are included when required. All minimum requirements for the accomplishment of any particular periodic maintenance task (preflight, post-flight, daily, calendar, special, or conditional inspection) or portion thereof, are contained in a set of these cards. The work plan, or order of performing the requirements, is prearranged in two manners. The preflight, postflight, and daily work is performed item by item in sequential order arranged on consecutively numbered cards. The calendar inspection work is controlled by the order of arrangement of the items on the MRC's, and in addition, employs a SCC (sequence control chart) for the scheduling of the MRC's. The calendar MRC's are scheduled on the SCC in numerical card number sequence for each required rating.

The man minutes and manhours indicated for the accomplishment of maintenance requirements are provided for use in work planning and scheduling. These figures do not include time spent in resolving equipment or parts shortages, adverse working conditions, nonscheduled maintenance, incorporation of changes and modifications, or shortages in numbers or qualifications of personnel. Time required for preparation is not included. There fore, maintenance supervisors should consider all such factors as they may apply locally when predicting aircraft out-of-service time.

Maintenance requirement cards are provided in separate decks; e.g., preflight, postflight, daily, and calendar. The MRC's contain all minimum requirements. Daily inspections include 14 days, 28 days, etc.; postflight inspections include "conditional" items, i.e., 100 arrested landings, hard landings, hot start, flameout, etc., and servicing requirements. The calendar MRC deck consists of a basic portion, called "calendar." These basic calendar requirements must be performed each calendar inspection. The odd and even calendar requirements are items that must be performed every other calendar inspection. These odd and even requirements have been divided to equalize the workload. For record purposes, these inspections are referred to as "odd" calendar and "even" calendar.

No part of any scheduled maintenance is certified on the maintenance requirement cards. Therefore, the MRC's will be used as many times as their condition permits. The certification by maintenance personnel is accomplished on the preflight/daily/in-flight/postflight maintenance record, NavAir Form 4730/2. The calendar periodic maintenance is certified on a MAF.

Locally established periodic maintenance requirements or requirements established by higher authority, not covered by the published MRC sets, can be added to existing cards, which will necessitate an adjustment to the individual card time, plus a possible adjustment of the sequence control chart if the card is in the calendar deck, or by the use of blank MRC's provided for this purpose (NavAir Form 4730/3), When using this method, the new cards generated at the local level can be numbered consecutively following the list number of the published deck (with the designation "local" or assigned suffix letters A, B, C, etc. and added to the number of the related cards of the published set (also with the designation "local").

A master file copy of current maintenance requirement cards must be maintained with the Maintenance Department. This master file copy will reflect all revisions to the published card sets plus locally added requirements. The Quality Assurance Group is normally charged with this responsibility.

Calendar Sequence Control Charts

In order to provide a guide for the preparation of the actual calendar maintenance work schedule and a means of controlling the assignment of work and personnel, calendar sequence control charts have been developed and provided as an integral part of the periodic maintenance program. These charts indicate what MRC's are to be complied with, the number and specialty of the personnel required, the times during which the separate jobs are scheduled for accomplishment, and the "power off", "power on" condition required during the work. The sequence charts have been planned to efficiently integrate all required calendar maintenance so as to effectively reduce the total out-of-service time required for the calendar inspection. The calendar sequence control charts provided may consist of one, two, or three sheets according to the requirements of the aircraft model. It should be noted that calendar SCC's have no application to the preflight, postflight, daily, or progressive aircraft rework requirements. A transparent plastic cover should be placed over the chart when in use to facilitate marking progress by the supervisor. The chart and the plastic cover are therefore reusable.

Special Inspection Requirements

All special inspections currently set forth in the applicable HIR or PMRM remain in effect at the specified interval. Such inspection may be performed concurrently with scheduled calendar inspections when the interval authorized for the special inspection is not exceeded. When the interval will be exceeded during the calendar inspection interval, the special inspection must be accomplished as part of the scheduled daily inspection falling nearest to the requirement. Once accomplished, a new interval for the special requirement commences.

SYSTEM MAINTENANCE AND TROUBLESHOOTING PROCEDURES

The Service Instruction Manual will contain procedures in the maintenance section which pertain to the maintenance and troubleshooting of the entire missile control system. The procedures will be given in step by step form for each of the systems within the equipment. Often the maintenance procedures will be presented in tabular form, and the troubleshooting procedures will ordinarily be presented in this manner.

Detailed system maintenance procedures are not discussed in this chapter. However, a brief discussion is presented for each system. When performing maintenance, the technician should always consult the Service Instruction Manual applicable to the equipment concerned for the proper step by step procedures, tolerances, and adjustments.

Power Supply Maintenance

The power supply system of a missile control system may contain several individual regulated power supplies. Each one is essential to the proper operation of the system and must be checked. There will normally be a power supply for the optical system and two in the ACD if used, and one or two in the radar equipment also one in the CW radar. The power supplies may contain a meter circuit which provides accurate indications of the output voltages.

Whenever there is trouble in the system, all power supply output voltages should be checked and adjusted according to instructions. No attempt should be made to adjust power supply output voltages with an external meter unless the meter has an accuracy of at least 0.1 percent over the required range. In analyzing power supply troubles, the trouble analysis chart should be consulted.

Transmitting System Maintenance

The transmitting system contains the PRF generating circuits, the modulator and magnetron, waveguide assembly, and the antenna. If antenna scanning is not desired at any time during maintenance, it can usually be stopped by actuating a switch. However, the feed horn and antenna rotation should not be stopped in any position where either will be pointing at a large close target while the system is transmitting.

The test equipment for maintenance of the system is chosen on the basis of its reliability, accuracy, and availability. Alternate test equipment should not be substituted unless the suggested equipment is not available.

The current and voltage reading given in the Maintenance Instructions Manual are absolute since test equipment may be substituted for the equipment specified. The tolerances of the test equipment and its effect on the circuit being tested must be considered before the circuit is either passed or rejected.

NOTE: RF radiation may have harmful effects on the eyes and other parts of the body. Therefore, personnel should stand clear of the radiation.

The trouble analysis charts for both the AI and CW transmitting system cover the most probable causes of trouble in the systems. When a trouble has been isolated and repaired, the test and alinement procedures should be repeated. If trouble analysis indicates that a major chassis is defective, it may be desirable to remove it completely.

Receiving, Range Tracking, and Antenna System Maintenance

Since the step by step maintenance procedures for each of these systems would be quite lengthy, they are not presented. However, for the most part, the discussion relative to the transmitting system maintenance also applies to these systems. In addition, when the technician is performing maintenance on the systems, the Maintenance Instructions Manual should always be referred to for the step by step procedures on each system. The procedures and trouble analysis charts and tables are similar to those of the transmitting system.

Indicating System Maintenance

The circuits of the indicating system may be divided into three parts–one for each of the guns of the CRT. Since these circuits are essentially independent, the test, alinement, and trouble analysis procedures are usually given separately. The procedures pertaining to the high voltage power supply will usually be covered in the A-gun procedures. If the high voltage supply appears to be defective during the check of the B- and C-gun circuits, then the high voltage portion of the A-gun check must be referred to again.

If the intensity controls are turned all the way up and no indication appears on the indicator and the high voltage supply checks out properly, the indicator either needs replacing or the voltages are not reaching the indicator.

The indicator intensity and focus adjustment procedures that are set forth in the Service Instruction Manual afford a relatively quick and reliable method for adjusting the indicator display for optimum visibility of all portions of the presentation. The adjustments may be made under any one of the following conditions:

1. Radome closed and transmitter radiating.
2. Radome open and transmitter radiating.
3. Radome closed and transmitter not radiating.

It may be necessary to remove access hole cover plates to reach the intensity and focus adjustments on the base of the indicator.

The tolerances of the displays presented by each electron gun and the conditions required to produce them are stipulated in the Service Instruction Manual. If each display falls within the specified tolerances, that portion of the indicating system is performing satisfactorily.

SUPPLEMENTARY MAINTENANCE

Complete maintenance of the entire missile control system requires maintenance procedures in addition to those discussed in the previous section. In the event that indications reveal erroneous operation of the ACS, optical system, or other associated components, or units, the applicable Service Instruction Manual may be consulted for the required procedures. The associated components as well as the main components of the system also have routine maintenance schedules and procedures that must be conducted. An electromechanical computer similar to the ACD, and a portion of a similar optical system is discussed in Aviation Fire Control Technician 3 & 2.

Some of the other procedures required for the complete maintenance of a missile control system are: boresighting, inspection, cleaning and lubrication, and pressurization checks.

Boresighting

The following discussions include three boresighting procedures and four groups of boresighting conditions. The primary boresighting reference to which the entire aircraft is alined is the zero-zero radar axis. That is the line in space along which the radar antenna will point when tracking a target with zero azimuth and zero elevation gimbal angles. The antenna is fitted with a boresight fixture to accept a telescopic sight for optical boresighting. The fixture can be used as a secondary reference after it is alined with the radar axis.

Satisfactory boresighting can be accomplished without radiating, provided the optical axis is in agreement with the RF axis of the radar antenna. This alinement will remain valid so long as no portion of the antenna structure is mechanically damaged. If there is reason to believe that the antenna has been mishandled, or if the feed horn or reflector appears to be deformed, a complete boresight should be conducted.

The first method of boresight is called full boresight and provides for a complete RF and optical boresight, as a result of which the state of alinement of the radar axis and optical axis is determined. The Service Instruction Manual should be consulted for the step by step procedure.

The second method is called radar silence boresight. It is the same as the first except that the telescope fixture is used as the only reference. This procedure can be used whenever it is impossible to radiate, or sufficient time does not exist for the full procedure.

The third method, called fast boresight, is only for use with the director portion of the aircraft armament. This method can be used only when the aircraft has been boresighted previously, using the full procedure with a given antenna. This method can then be used to establish the electrical boresight of the director.

Inspection

A visual inspection of a missile control system should be held during the regular aircraft maintenance period. If the system has been operating satisfactorily and meets the requirement of the 10-hour minimum performance checks, the inspection should be carried out to the extent possible without removing any components from the aircraft or otherwise disturbing them. A more thorough inspection can be performed when the system is removed to the bench desiring the calendar maintenance schedule. All input power to the system should be removed. When the inspection indicates the necessity, the equipment should be cleaned in accordance with instructions. Parts found to be defective should be repaired if economically feasible or if replacement is not obtainable; otherwise the parts should be replaced.

Some of the defects to look for are as follows:

1. Corrosion, fungus growth, salt, or other mineral deposits.
2. Evidence of overheating, such as charring or melting
3. Excessive moisture accumulation.
4. Broken, bent, loose, or missing parts.
5. Improper seating of plug-in components, such as connectors and plug-in units.
6. Binding or looseness of controls on the cockpit control panel.
7. Abrasion of wires and cables, giving particular attention to interconnecting cables.
8. Soiling of optical sight lenses and glass surfaces.
9. Antenna reflector and feed horn damage.

Inspection procedures for parts requiring special considerations are always given in the Service Instruction Manual.

Cleaning and Lubrication

Ordinarily, the equipment should require only dusting with a clean, dry, lint-free cloth and a dry, low pressure compressed airstream. A minimum of solvents or other cleaning agents should be used when cleaning. Lubrication and lubricants to be used should be in accordance with instruction in the Service Instruction Manual.

Pressurization

The waveguide assembly, modulator, and radar indicator are pressurized to avoid arcing and moisture accumulation problems. These components should be checked regularly for air leaks. (The following discussion is relative to a typical system and may differ in some respects from other pressurization systems.)

The waveguide assembly and the modulator are pressurized by bleed air from the last stage of the aircraft engine compressor whenever the engine is running. The bleed air is reduced in pressure by a reducer prior to being fed into the equipment compartment of the aircraft. Air from the reducer is passed through a rigid air line which is terminated in a quick disconnect fitting that mates with a fitting in the rear of the radar frame. This fitting connects to a dehydrator by way of a rigid air line. The dehydrated air is then fed through a flexible hose to a fitting on the waveguide assembly. Air is then carried to the modulator through a line from the other end of the waveguide assembly.

After engine shutdown, pressure in the waveguide assembly and modulator should decrease at a specific rate. Air loss should be checked at every inspection at the fitting on the modulator, using an air pressure page. If the waveguide or the modulator cover has been opened, or if the aircraft has been standing for some time after engine is shutdown, it will be necessary to repressurize before a check can be made. When the loss is excessive, check for security of the modulator cover, flexible waveguide fittings, and air line fittings. If the checks of the seating of the rigid waveguide coupling flanges do not reveal the trouble, the leak may be in the compressor bleed air system.

When checking pressurization, also observe the color and level of the desiccant crystals in the dehydrator. If the crystals have turned pink, new crystals should be substituted. If necessary, the old crystals may be reactivated by baking until they turn blue. New crystals should be added when the crystal level has fallen below the safe mark.

The indicator is pressurized initially at a specific pressure and should maintain this pressure at all times with no appreciable loss. Repressurization is required if the rear cover of the indicator is removed for servicing. The indicator pressure should be checked in the course of each preflight inspection. If pressure loss is detected, check the security of cover plates and gaskets for air leakage. Dry air should be used for pressurizing the indicator.

CW RADAR SET GROUP

Organizational maintenance of the CW radar set group comprises mainly of general electronic maintenance procedures utilizing the applicable Service Instruction Manual.

The technician should have a thorough knowledge of the operation of the equipment with which he is concerned; however, he cannot always relay on his memory for specific procedures, tests, alinements, test equipment readings, and tolerances. Therefore, the Service Instruction Manual should always be consulted when working on equipment. On occasion it may be necessary to consult several manuals; for example, the complete system manual, radar set manual, computer group manual, and possibly the manuals for the test equipments. In addition, it may be necessary to consult the Maintenance Instruction Manual for the aircraft in which the equipment is installed.

Tests

Specialized test equipment is normally used during checks on the CW radar set group. Newer systems have BIT (Built-in-Tests) checks which check the system for proper operation with readout in the form of either scope presentations or lights. When an error is indicated, further examination is made by utilizing the proper test equipment. A missile simulator test set is used to verify that the system will properly tune a missile. The test set monitors the missile system control functions generated in the aircraft and provides signals for checking the missiles klystron tuner. During these tests the aircraft wiring associated with the missile is also checked.

The Modulation Test Set is used for checking the output of the CW transmitter. The output of the transmitter is fed into the test set by a coaxial cable and the test set indicates various signal characteristics with their values and tolerances by receiving and interpreting the microwave signals. The outputs are indicated on ammeters located on the front panel of the test set.

The Computer-Radar Test Set is designed to check certain aspects of flight readiness of the CW and associated AI radar. The monitoring capabilities are as follows:

1. Computer outputs which result from problems generated by the test set.
2. AI radar and flight data unit outputs applied to the computer.
3. The proper function of miscellaneous circuits which contribute to the flight readiness status.

CHAPTER 15

BOMB DIRECTOR SYSTEM

A typical airborne radar-optical bombing system capable of high altitude precision bombing from high-speed aircraft is discussed in this chapter. The system also includes operational features which make it useful during the entire flight by providing search and navigation information. It solves the bombing problem in a manner that minimizes the operational procedures required of the pilot and bombardier during the bombing run. Its major characteristics are as follows:

1. Both a periscope and a radar antenna are continuously positioned on the area of interest to permit the bombardier either optical or radar operation at his discretion.
2. The optical line of sight and the radar beam are stabilized against aircraft rotations to permit tracking in a stable reference frame.
3. Precision tracking is performed automatically after the bombardier has correctly positioned the crosslines on the aim point.
4. Offset bombing of a stationary target is possible when the target is hidden or obscure.
5. Evasive maneuvers can be performed by the pilot during the bombing run.
6. Provisions can be made for an autopilot tie-in which permits automatic control of the aircraft by the system during the bombing run.
7. Bomb bay doors are opened, bombs are released, and bomb bay doors are closed automatically.
8. A ground position indicator automatically furnished navigation data in the form of latitude and longitude of the aircraft's present ground position.

The general bombing problem that must be solved in order to hit a target basically involves the determination of (1) the position of the target with respect to the aircraft at every instant, and (2) where the bomb would hit if released at any given instant. The major components of a typical bomb director system used for the solution of the bombing problems are illustrated in figure 15-1.

OPTICAL SYSTEM

Because optical and radar tracking phases need to be clearly differentiated, each is discussed separately in this chapter. This complete treatment of optical tracking also covers transmission of radar presentation from the cathode-ray tube in the indicator to the periscope eyepiece.

The primary function of the optical system is to enable the operator to track an aim point by optics or radar. The operator selects either the optical or the radar presentation for observation and photographs the selected display if desired. As will be shown later, the radar image is transferred from the indicator to the periscope.

(Note: It should be recalled from Chapter 17 of Aviation Fire Control Technician 3 and 2, NavPers 10387, that range and bearing data are fed to the bombing computer from either the optical or radar system.)

The optical system is illustrated by block diagram in figure 15-2. It consists of (1) the optical elements which transmit either optical or radar presentation to the operator and tracking recorder, (2) the tracking recorder which photographs the presentation being observed, and (3) the electromechanical drive system which positions the optical presentation.

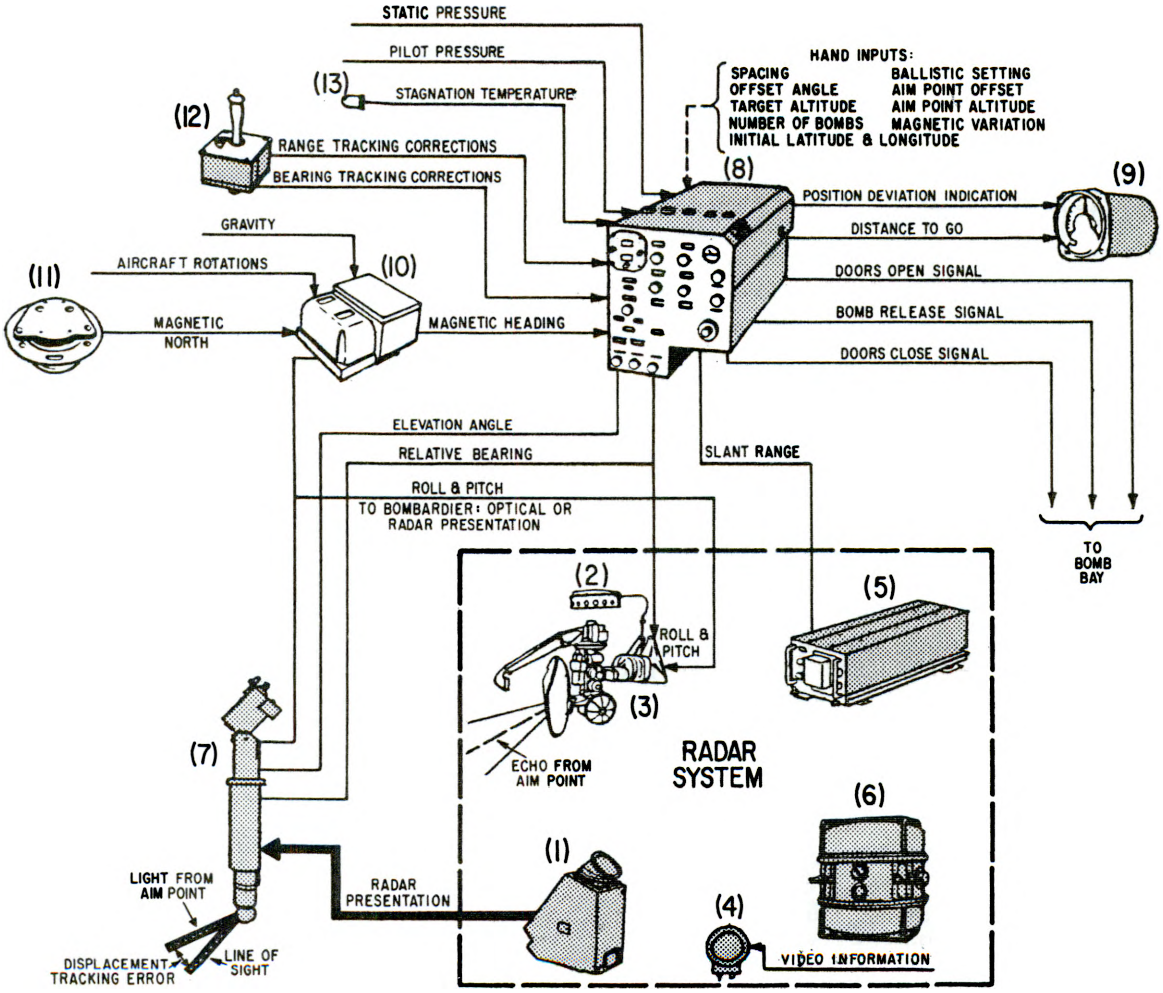
OPTICAL ELEMENTS

The optical elements contain two optical systems—one presents an optical image of the aim point at the eyepiece, and the other presents an image of the radar screen at the eyepiece. A mirror in front of the eyepiece can be positioned to divert either image to the recording camera. The function of the elements used in the optical presentation is to form a clearly defined image of the aim point, relay it through the instrument, magnify it, and present it in an erect position. Light from the target may be received from any direction within the limits of the equipment.

The optical presentation uses the nine major assemblies shown in figure 15-3. These assemblies are the corrector lens, the sighting prism, the objective lens and reticle, first and second erector lens, derotation prism, the deviation prism and fourth erector lens, and the eyepiece. In figure 15-3, the distances between elements have been greatly reduced.

The radar presentation uses three assemblies–the radar objective lens, two color filters, and the eyepiece. These three assemblies are in the upper section. The same eyepiece is used by both systems.

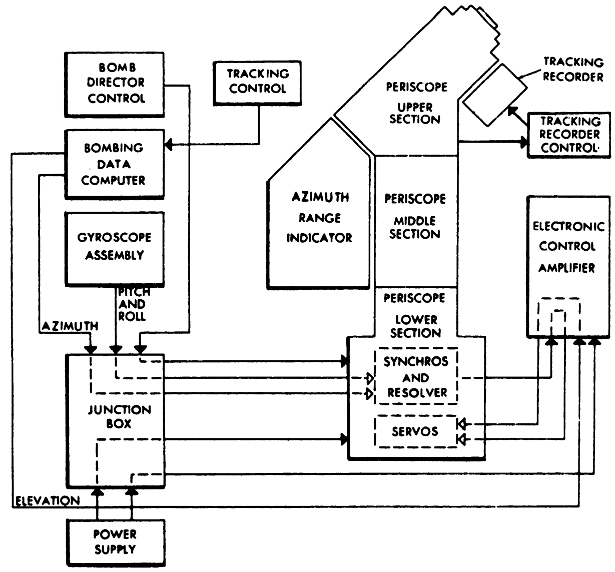
The optical assemblies are discussed in the following paragraphs. Reference should be made frequently to figure 15-3 to insure an understanding of the relationship of each assembly to the others.



AQ. 290

Figure 15-1.–Components of a bomb director system.

1. Indicator, azimuth-range.
2. Receiver-transmitter.
3. Antenna.
4. Auxiliary indicator.
5. Synchronizer, electrical.
6. Modulator.
7. Periscope.
8. Bombing data computer.
9. Position deviation indicator.
10. Gyroscope assembly.
11. Magnetic compass.
12. Tracking control.
13. Temperature element.



AQ. 291
Figure 15-2.–Optical system simplified block diagram.

Corrector Lens

Light from the aim point enters the periscope through the glass globe that encompasses the sighting head. Since the first sighting prism to receive the light is not at the center of the globe but offset in a direction perpendicular to the optical axis, a corrector lens is required to compensate for the deviation of the light introduced by the globe. The corrector lens is mounted on the holder of the first prism and moves with it.

Sighting Prism

The sighting prisms consist of two totally reflecting right-angle prisms. When the prisms are in the position shown in figure 15-3, each diverts the line of sight through 90°, thus maintaining the line of sight parallel to the optical axis of the periscope. The position shown represents zero inputs of level and cross level at 90° elevation. (Level and cross level are defined later in this chapter.)

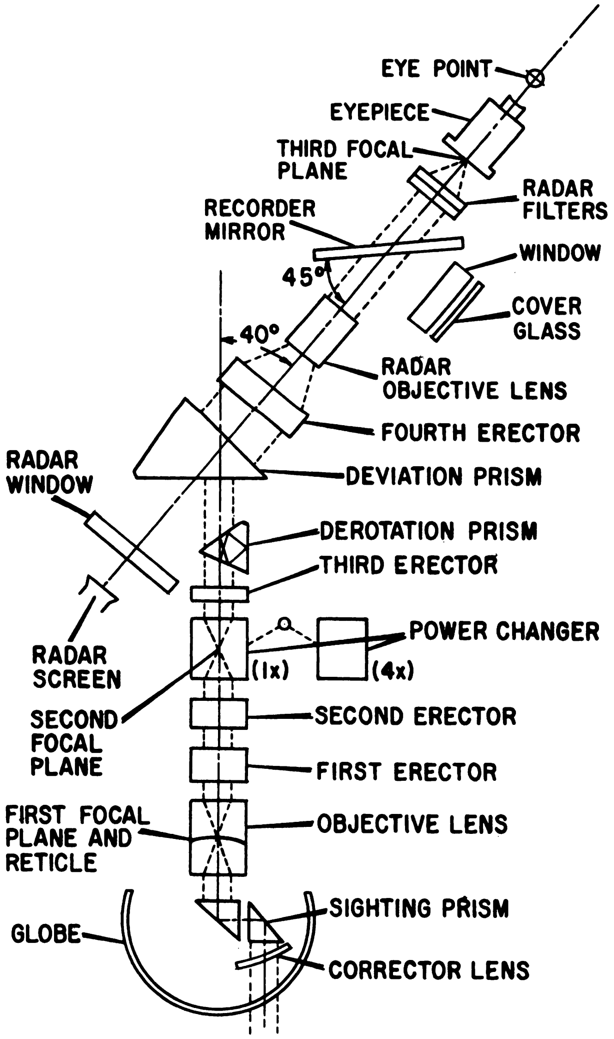
Objective Lens and Reticle

The objective lens receives parallel light rays from a distant target, in effect, at infinity, since the sighting prisms do not focus but simply displace the path of light rays. The light rays are thus focused for the first time by the objective lens at the point designated as the first focal plane.

The reticle is etched on one side of a glass-to-glass surface in the reticle lens assembly. This surface coincides with the first focal plane so that a sharp image of the reticle crosshairs is superimposed on the target image.

First and Second Erector Lenses

The first focal plane of the periscope is also the front focal plane of the first erector lens. Light rays entering the first erector



AQ. 292
Figure 15-3.–Periscope optical system, block diagram.

lens from the first focal plane therefore emerge as parallel light rays. These are transmitted to the second erector lens assembly located in the middle section of the periscope.

Power-Changer Lenses

The second erector lens and front elements of the power-changer lens form a second image of the target in the middle of the power-changer lens. This is the second focal plane. Either of the two power-changer lens assemblies may be used in the system as desired by the operator. The low-power lens, shown positioned in the optical line of sight in figure 15-3, provides a 1x magnification. The high-power lens provides a 4x magnification. Since the total magnification of the system is 1.5x, the operator has a choice of either 1.5x or 6x power.

Third Erector Lens

The third erector lens and rear elements of the power-changer lens comprise a system in which the front focal plane coincides with the second focal plane of the periscope. Therefore, parallel light rays emerge from the third erector lens and are transmitted to the derotation prism.

Derotation Prism

The derotation prism has two functions. The first function is to compensate for tumbling of the image which occurs when the first sighting prism rotates in relation to the second prism in level and elevation, or when the sighting head rotates in azimuth. The prism has the optical characteristic of inverting an image in only one plane without deviation or dispersion if placed in parallel light. If the object being viewed through the prism is rotated and the prism is rotated in the same direction but at half the speed, this optical characteristic will produce an image which remains fixed or derotated. The result is the elimination of image rotation with references to the eyepiece and the operator.

The second function of the derotation prism is to invert the image in one plane. It is so related to the deviation prism, the next optical element in the system, that it inverts the image in one plane while the deviation prism inverts in the other plane, thus producing complete inversion. This inversion, when combined with the inversion caused by the objective lens and the double inversion of the two erecting lens system, produces an erect image at the eyepiece.

Deviation Prism and Fourth Erector Lens

The parallel light rays enter the deviation prism from the derotation prism where they are refracted, reflected three times by the prism faces, and refracted again. The light rays emerge inclined 40° from the original optical axis (fig. 15-3). The fourth erector lens then focuses the image of the target in the third focal plane in front of the eyepiece.

RADAR PRESENTATION

If the operator wishes to view or record the image displayed on the azimuth range indicator (main indicator), he may do so by positioning the radar objective lens in the upper section of the periscope.

Radar Objective Lens

When the radar objective lens assembly is pivoted into position for radar presentation, it forms an image of the radar screen in the third focal plane. The image is received through a window in the upper housing of the periscope, as shown in figure 15-3.

The radar objective lens, the fourth erector lens, and the deviation prism are so mounted on the same carrier that for radar presentation the deviation prism and the fourth erector lens are out of the optical axis; for optical presentation, the radar objective lens is out of the optical axis. The recorder mirror is out of the field of view except when the recorder is actuated.

Color Filters

Two radar filters, one yellow and one blue, are mounted on the radar transfer mechanism so that either one may be swung into the optical axis in front of the eyepiece when viewing radar. As discussed previously, each filter is actuated by a rotary solenoid. When the mechanism is positioned for radar operation, the filter control switches are actuated, operating the solenoids to position the filters.

The selection of filters is automatically controlled by the computer, depending upon the computed range to the target.

Eyepiece

The optical or radar image presented in the third focal plane is viewed by means of the eyepiece. The position of the front focal plane of the eyepiece is adjusted by the individual operator so that the virtual image formed by the eyepiece is distinct. For the normal eye this position is coincident with the third focal plane, as shown in figure 15-3. At this position the light rays emerging from the eyepiece are in parallel rays, and the eyepiece or the focal plane of the tracking recorder is said to be focused for infinity. The eyepoint, or the point on the optical axis where the iris of the eye is placed to receive the full field of view, is the point at which the chief rays of the parallel light emerging from the eyepiece are concentrated.

TRACKING RECORDER

The tracking recorder is mounted on the upper section of the periscope just below the eyepiece. (See fig. 15-1.) Its function is to provide a photographic record of the optical or radar display of the target image. The recorder-mirror mechanism diverts the target image from the eyepiece to the recorder through a window in the periscope.

The recorder and control box are illustrated in figure 15-4. The hinged front cover provides access to the film magazines. Access to the two lamps, which illuminate a watch face and film-frame counter, is provided by the bottom cover. The top cover contains the glass window, which is the camera aperture, and the fittings for attaching the recorder to the periscope. The rear cover protects the film drive mechanism. The aperture of the tracking recorder is closed by one of two metallic shutter curtains when the recorder is is not in operation. The shutters are controlled by two linear electric motors which are controlled timewise by the tracking recorder control setting for exposure time.

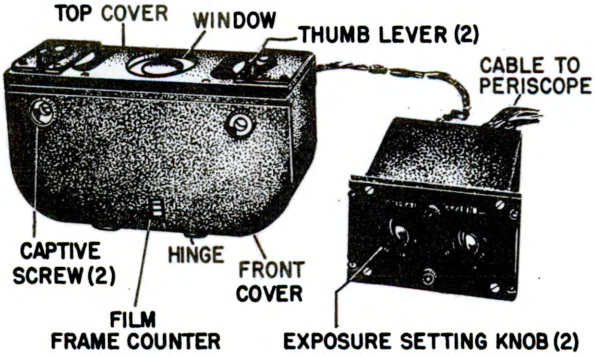


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Figure 15-4.—Tracking recorder and tracking recorder control.

The film advance motor and the gear train are located near the rear of the case. The motor is geared to the drive sprocket and to the magazine spindle. It also drives the film counter.

The recorder is designed to use 70 millimeter film on 100-foot standard reels. The reels are contained in lighttight magazines which, in turn, fit into wells. A square spindle extends from the bottom of the magazine fitting into a socket in the bottom of the well. The film is threaded across two sprockets on either side of the aperture and below a pressure pad which keeps the film in the focal plane.

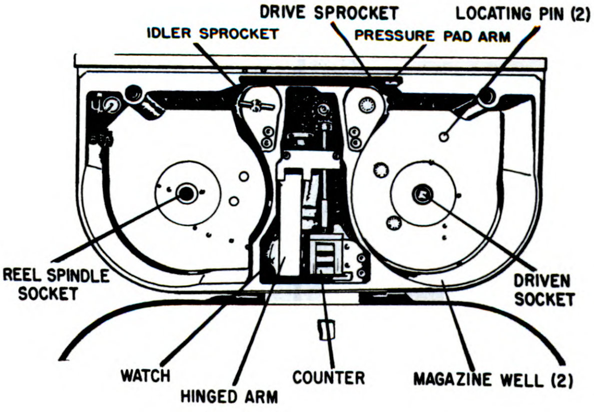

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Figure 15-5.—Tracking recorder, front cover open.

Figure 15-5 shows the tracking recorder with the front cover open and the film magazine removed. A watch and a film-frame counter are shown at the bottom of the case. The illumination lamps are mounted in the rear of the case. The watch is on a hinged arm so that it can be pivoted out for winding and setting. Images of the watch face and film counter are projected to the film plane through the back of the film by a prism and lens assembly.

ELECTROMECHANICAL DRIVE SYSTEM

The electromechanical drive system, located in the lower section of the periscope, consists of a stabilizing mechanism and driving mechanism which cause the periscope to track the aim point. The electromechanical drive system consists mainly of four servo loops, an electrical resolver, and the drive motor and circuit required to position the deviation prism.

The four servo loops use amplified electrical error signals from associated equipment to position elements within the periscope which stabilize the line of sight. (The relationship of the periscope to other components of the bomb director and associated equipment was illustrated in figure 15-1.)

However, before going into the operation of the electromechanical drive system, the angles associated with the system should be defined. They are as follows:

1. Azimuth–the angle between the vertical plane through the fore-and-aft axis of the aircraft and the vertical plane through the line of sight measured in the horizontal plane.
2. Pseudoazimuth – the angle between the vertical plane through the fore-and-aft axis of the aircraft and the vertical plane through the line of sight measured in the deck plane of the aircraft.
3. Pitch–the angle between the horizontal plane and the deck plane of the aircraft measured in the vertical plane through the fore-and-aft axis.
4. Roll–the angle between the horizontal plane and the deck plane of the aircraft measured in the plane perpendicular to the fore-and-aft axis of the aircraft.
5. Level–the angle between the horizontal plane and the deck plane of the aircraft measured in the vertical plane through the line of sight.
6. Cross level–the angle between the horizontal plane and the deck plane of the aircraft measured in the plane perpendicular to the deck plane of the aircraft and perpendicular to the vertical plane through the line of sight.
7. Elevation–the angle between the line of sight and the vertical.

Referring to figure 15-6, it should be noted that the output from the pitch synchro control transformer is combined with the output from the roll synchro control transformer in the resolver. The purpose of the resolver is to derive values of level and cross level from inputs of pitch, roll, and azimuth. The resolver circuit is illustrated in figure 15-7.

It is necessary to resolve the values of roll and pitch into values of level and cross level due to the input values of pseudoazimuth. When the azimuth angle is zero, pitch will equal level and roll will equal cross level, since the line of sight and the fore-and-aft axis of the aircraft are in parallel vertical planes. However, for azimuth angles other than zero, the values of the roll angle and the pitch angle vary about the optical axis so that the angular values of pitch and level and roll and cross level vary as

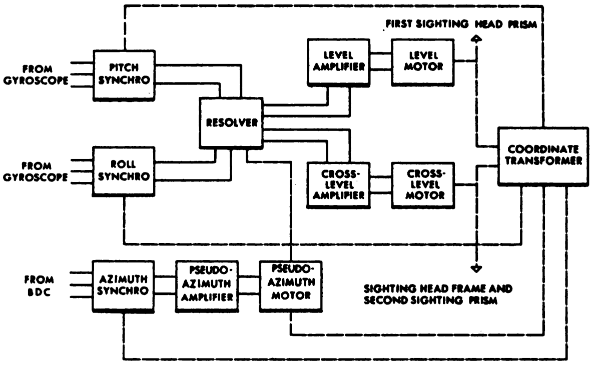

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Figure 15-6. –Servo circuits block diagram.

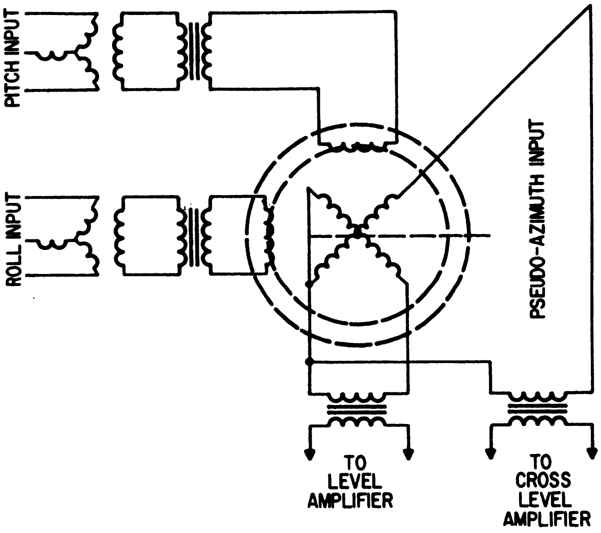

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Figure 15-7. –Resolver circuit.

a function of the azimuth angle. In other words, with an azimuth angle of 90°, pitch would become roll, and roll would become pitch.

Referring to figure 15-7, note that values of pitch and roll are coupled to the input windings which are physically positioned to form angles 90°. Since the rotor is physically positioned by pseudoazimuth, the resolver transfers the input voltages from one set of coordinates, and the angular distance separating these sets of coordinates is azimuth. The electrical relationship of the voltages in the resolver is thus directly analogous to the physical relationship of the gimbals and rings in the coordinate transformer.

Voltages representing level and cross level position errors are simultaneously developed across their respective windings in the resolver. The level servomotor, energized by the level amplifier, positions the first sighting prism and the level gimbal of the coordinate transformer. The cross level servomotor, energized by the cross level amplifier, positions the sighting-head carriage, the second sighting prism, and the cross level ring of the coordinate transformer. (See fig. 15-8.)

The pseudoazimuth motor is geared to the azimuth structure and rotates until the structure has turned through the angle received by the azimuth synchro. (See fig. 15-9.) The azimuth synchro is mounted on the pitch gimbal which does not rotate with the azimuth structure. The synchro rotor is geared to the level ring which is mounted on, and rotates with, the azimuth structure. Therefore, rotation of the azimuth structure repositions the synchro rotor and nulls the azimuth error signal.

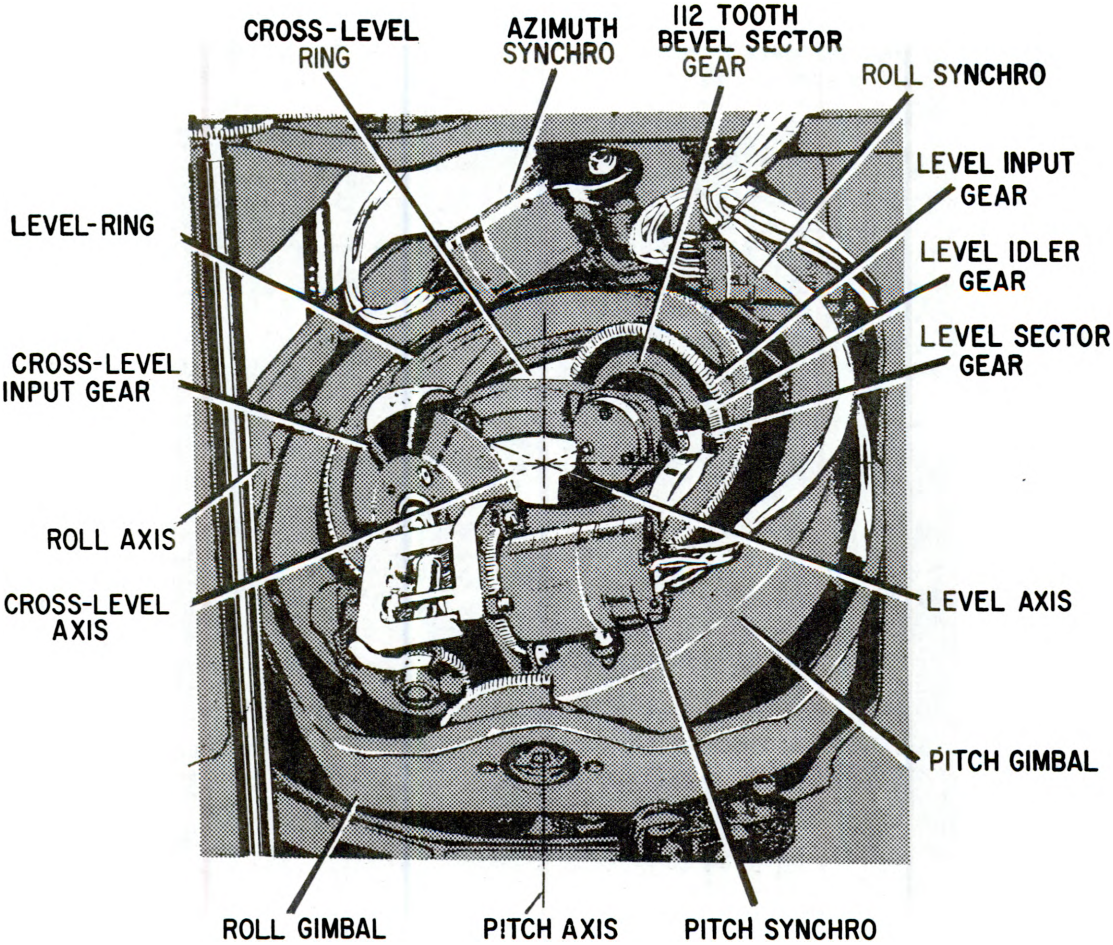

Figure 15-8. —Coordinate transformer.

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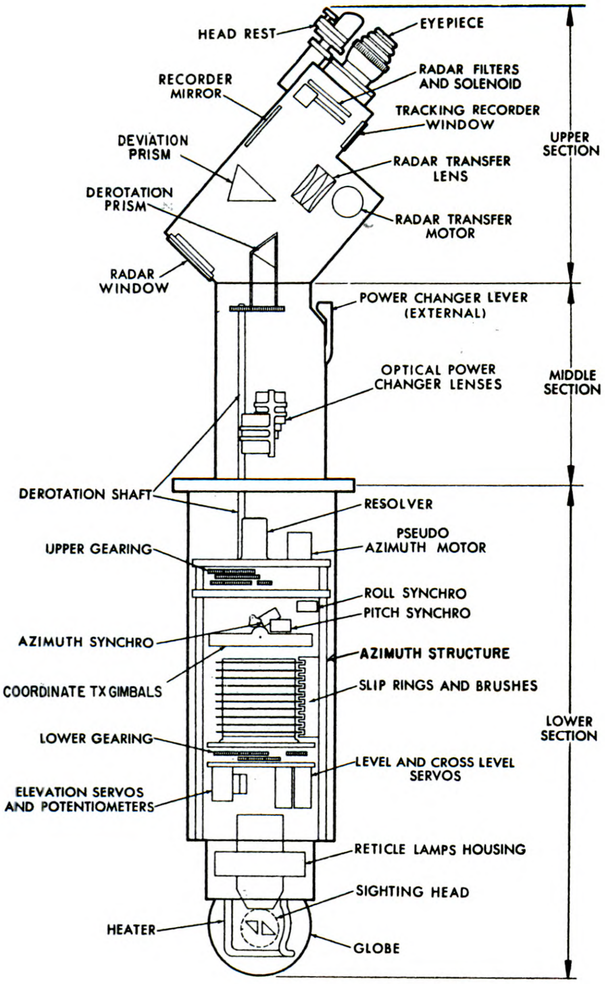

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Figure 15-9. –Arrangement of periscope components.

For each combination of the inputs of azimuth, roll, and pitch, there is one set of level and cross level values. The corrdinate transformer (fig. 15-8) is constructed to reproduce these angular relationships mechanically, and to make possible the physical resetting of the pitch and roll synchro control transformer's rotors and the nulling of error voltages. The pitch synchro control transformer is mounted on the pitch gimbal, and its rotor is geared to the roll gimbal. Since the angle between these two gimbals represents the pitch angle, the synchro rotor is repositioned by a motion representing pitch, and the error signal is nulled. The roll synchro control transformer is mounted on the periscope frame, and its rotor is geared to the roll gimbal. Since the angle between the frame and the roll gimbal represents the roll angle, the synchro rotor is repositioned by a motion representing roll and the error signal is nulled.

The fourth servo loop is used to compute elevation angle ϕ which is part of the slant range and elevation angle system. (The system was discussed in chapter 17 of Aviation Fire Control Technician 3 & 2. The elevation servo loop (fig. 15-10) consists of a potentiometer bridge circuit, and electronic amplifier, and a servomotor. A d-c voltage supply, controlled by variable resistor R1 is applied to the bridge circuit. One leg of the bridge circuit is located in the bombing data computer (PR1 and PR2), and the other leg is located in the periscope. If the combined resistance of PR1 and PR2 is equal to the combined resistance of R3 and R4, the voltage drops across the legs of the bridge are equal and no voltage is impressed upon the elevation amplifier.

The movable contacts of PR1 and PR2 are physically positioned by a motion proportional to elevation inputs from the bombing data computer. Motion of these contacts unbalances the bridge and causes a voltage to appear across the amplifier input circuit. This voltage is amplified and energizes the servomotor. Rotation of the servomotor positions one side gear of a differential, where elevation is combined with level to position the sighting head, and repositions the movable contacts of potentiometers R3 and R4 until the bridge is balanced and the voltage becomes zero.

The stabilization limit switch is located in the lower section of the periscope. The switch closes when a stabilizing input from the gyro tilts the level ring of the coordinate transformer out of its designed limits. When actuated, the switch places three resistors in series with the fixed fields of the level and cross

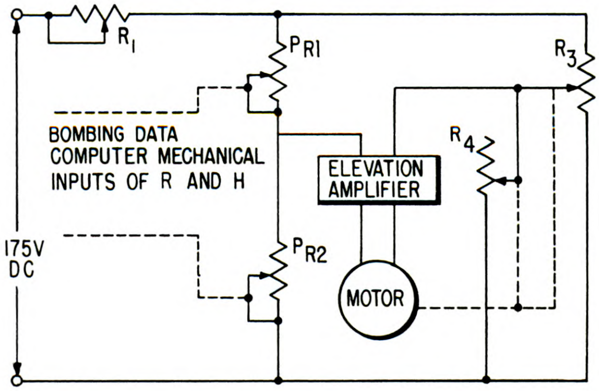

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Figure 15-10. –Elevation servo loop.

level servomotors. The purpose of these resistors is to reduce servomotor power so that the mechanism will not be damaged by driving against the mechanical limits of gimbal motion. The power reduction remains in effect as long as the stabilizing input from the gyros is in excess of the gimbal limits.

Radar Transfer Mechanism Control Circuits

The radar transfer mechanism is driven by a motor which is controlled by the function switch on the combing data computer and by limit switches located in the upper section of the periscope. The two limit switches are actuated by the radar transfer mechanism which provides either radar or optical presentation to the operator.

The radar transfer mechanism also actuates the SHUTTER TIMING control switch and the filter control switches. The SHUTTER TIMING control switch is a two-position switch which determines whether the optical or radar shutter timing control circuit in the tracking recorder control is used.

The periscope contains two optical filters. one blue and one yellow. Each filter is controlled by a rotary solenoid. The solenoid supply circuit operation determines which of is in the optical axis. When the system is on optical mode of operation, both filters are swung out of the optical axis. When the radar transfer mechanism is driven to the radar position and the radar is in the SEARCH or EXPANDED position on the long range operation, the yellow filter is in the field of view. When the radar is in the EXPANDED position on short range operation, the blue filter is in the optical axis and the field of view.

Recorder-Mirror Circuit

The recorder-mirror mechanism, located in the upper section of the periscope, is powered by two rotary solenoids. Solenoid action is initiated by either a momentary contact switch on the bomb director control or from a signal originating in the bombing data computer at release time. During this period of time the recorder mirror directs the image light into the tracking recorder for recording purposes, and the aim point image is not available to the operator. The solenoids are deenergized after both shutters of the tracking recorder have been actuated and the film advance motor is energized by a switch located in the tracking recorder.

PERISCOPE MAINTENANCE

The periscope is designed and constructed to require a minimum of maintenance. It should, however, be checked and serviced periodically to insure satisfactory operation. Those parts of the equipment which are accessible without disassembly should be inspected immediately before and after installation and regularly thereafter regardless of apparent good condition, lack of use, or recent servicing. These items include the following components:

1. All cabling and electrical connectors between the periscope, accessory equipment, electronic control amplifier, and junction box.
2. Tubing between the periscope and air dryer.
3. Reticle lamps.
4. Humidity indicator for leaking air seals or malfunctioning of the dryer, heating element, or thermostatic switch.

Reticle Lamp Servicing

Eight lamps connected in parallel provide reticle illumination. These lamps must be viewed through the reticle lamp access port to determine if all are lighted. Two access ports are provided in the lower section of the periscope just above the sighting head. At least one of these two ports should be accessible for servicing. Remove the access plug. With the reticle lamp circuit energized, a defective lamp will be readily apparent, since the ends of the reticle lamp sockets are constructed of translucent plastic.

All eight lamps can be checked by rotating the azimuth structure from within the aircraft and viewing each of the eight sockets in turn through the access port. To remove the access port and replace defective reticle lamps, follow the procedures as outlined in the equipment's Service Instruction Manual.

Air Seal Replacement

The periscope is enclosed in an airtight housing to keep optical and mechanical parts free of moisture. O-ring seals or gaskets are required at various locations to maintain the air-tight condition. The majority of the seals are located in regions which are accessible without disassembling the individual sections for replacement. The few remaining locations are inaccessible, and faulty seals in these areas should be replaced only by an authorized repair facility. The presence of moisture inside the periscope which cannot be accounted for by malfunctioning of the heater or thermostatic switch is probably the result of defective air seals. All data required for the upper, middle, and lower section removal, adjustment, and replacement procedures as well as data required for locating and replacing air seals, are presented in the equipment's Service Instruction Manual and should be closely followed when disassembling or assembling the periscope.

TROUBLE ANALYSIS

This section contains information on trouble analysis that falls within the area of field maintenance procedure for the periscope. With the exception of those defects for which servicing procedures are described, defects that develop within the periscope will normally require replacement of the instrument, a section of the instrument, or accessroy equipment.

Trouble within the periscope will normally be indicated by the following symptoms:

1. The appearance of moisture on the optical parts or a pink color in the humidity indicator.
2. Lack of image clarity.
3. Motion of the image under normal tracking conditions.
4. Undue vibration of the instrument.

Moisture

Check the humidity level of the air inside the periscope regularly by comparing the color of the humidity indicator crystals with the humidity color shade which represents 40 percent humidity. If servicing is indicated, proceed as follows:

1. Check the heater for proper operation. If it is not operating, replace both the heating element and the thermostatic switch located in the sighting globe.
2. If the heater is operating properly, check the instrument dryer loop for proper operation.
3. If the humidity level still exceeds the specified maximum after performing the above, inspect the air seals and replace where necessary. If excessive humidity still exists, replace the instrument.

Lack of Image Clarity

If the image is not clear or if spots or lines are superimposed over the image, clean the sighting-head globe and the eyepiece with optical tissue. If the radar image is not clear or is spotted, clean the radar window and screen with optical tissue. If the trouble is not remedied by the foregoing treatment, replace the instrument.

Image Motion

If the periscope fails to track properly, check the electronic control amplifier units, using the appropriate maintenance publications as a reference. If the trouble cannot be traced to the electronic circuits, replace the instrument.

Vibration

Undue vibration of the periscope or of the image may be due to loose mounting bolts which mount the instrument to the aircraft, or accessory equipment to the instrument. If vibration occurs, inspect all mounting bolts and tighten if necessary.

Electrical Trouble Analysis

The normal continuity checks, voltage checks, and signal tracing methods of electronic equipment troubleshooting should be used in checking the cabling and electronic components of the instrument. These checks may be made by using the information given in the schematic wiring diagrams contained in the equipment's Service Instruction Manual.

RADAR SYSTEM

The primary purpose of the complete radar system is to permit radar tracking of an aim point during a bombing run. It also provides facilities for radar search, navigational beacon location, and for calibration the bombing data computer. When the radar is used for tracking purposes, the radar system forms a part of the tracking loop which also includes several subcomponents of the bombing data computer.

During radar tracking, the radar system measures the slant range and relative bearing of the aim point and presents this information to the bombardier in the form of an indicator presentation. Computed values of range and relative bearing are received from the bombing data computer and are converted by the radar set into a RANGE LINE and a AZIMUTH LINE, respectively, for the presentation on the indicator. Any difference between the measured and computed values of range and relative bearing appears on the indicator as a displacement of the aim point from the intersection of the range and azimuth lines.

Range and azimuth corrections are introduced to change the generated values of range and relative bearing until the generated values are equal to the measured values. This condition exists when the aim point image is intersected by the range and azimuth lines.

FUNCTIONAL ANALYSIS

In chapters 5 through 10 of this course a circuit analysis of the major components of a fire control radar was discussed. In this section, the operation of the radar components is grouped by the function they perform. It is not the intent of this discussion to cover the complete theory of operation of the radar system, but to familiarize the AQ1 and AQC with a functional analysis of the equipment and to tie in the major components previously discussed.

Transmitting Functions

The components and their sections of the radar system used during transmitting time are illustrated in block form in figures 15-11 and 15-12. These diagrams should be referred to as the various transmitting functions are discussed.

The master trigger circuits generate a master trigger pulse for timing the entire system. The master trigger pulse (fig. 15-11) is fed to the modulator delay circuits. The modulator delay circuits generate the modulator trigger, which is delayed with respect to the master trigger by an amount necessary to provide the zero-set calibration. The modulator trigger is amplified and shaped by the trigger amplifier circuit (blocking oscillator and cathode follower) and fed to the thyratron switch.

The pulse-forming network (PFN) produces the modulating pulse and the high-voltage power supply is used to charge the PFN during transmitter rest time. When the thyratron switch tube receives the modulator trigger, it causes the network to be discharged. The variable autotransformer provides a means of varying the primary a-c voltage to the power supply, and thus permits control over the d-c output voltage and the amplitude of the modulating pulse. The magentron receives its input power from the modulating pulse; therefore, since the variable autotransformer controls the amplitude of the modulating pulse, it also controls the RF power output of the magentron. The magnetron tuning mechanism provides a means of tuning the magnetron to any frequency within its designed limits. (Refer to fig. 15-12.) When beacon operation is selected, the mechanism automatically tunes the magnetron to the beacon frequency. When radar interference such as jamming is encountered at any particular frequency during search operations, the tunable feature makes possible a change to some other frequency at which the interference is not present. The RF output pulse is fed through the load and the AFC sampler to the waveguide switch.

The load isolator prevents any of the transmitted energy which may be reflected from mismatched RF couplings from passing to the magnetron. If the reflected energy were allowed to pass to the magnetron, the frequency would be likely to change, resulting in a probable loss of power output.

The AFC sampler supplies a small sample of the transmitted pulse for the AFC section of the receiving channel.

The waveguide switch directs the RF pulse along either of two paths. One path leads through the duplexer and one of the directional couplers to the antenna feed horn, and the other path leads through the second directional coupler to the dummy load. The pulse is directed along the first path when the RF energy is to be radiated, and along the second path when it is desirable to prevent radiation but still keep the magnetron operating.

When the magnetron pulse is switched to the antenna, the duplexer prevents the high-power pulse from passing to the receiver mixer. The directional coupler, which is in the path between the duplexer and the antenna, provides a means of either extracting a sample of the transmitter pulse for testing, or inserting a signal for testing the receiving channel. During operation this directional coupler is connected to the tuned cavity, which is discussed later in the analysis. Most of the magnetron energy passes through the directional coupler

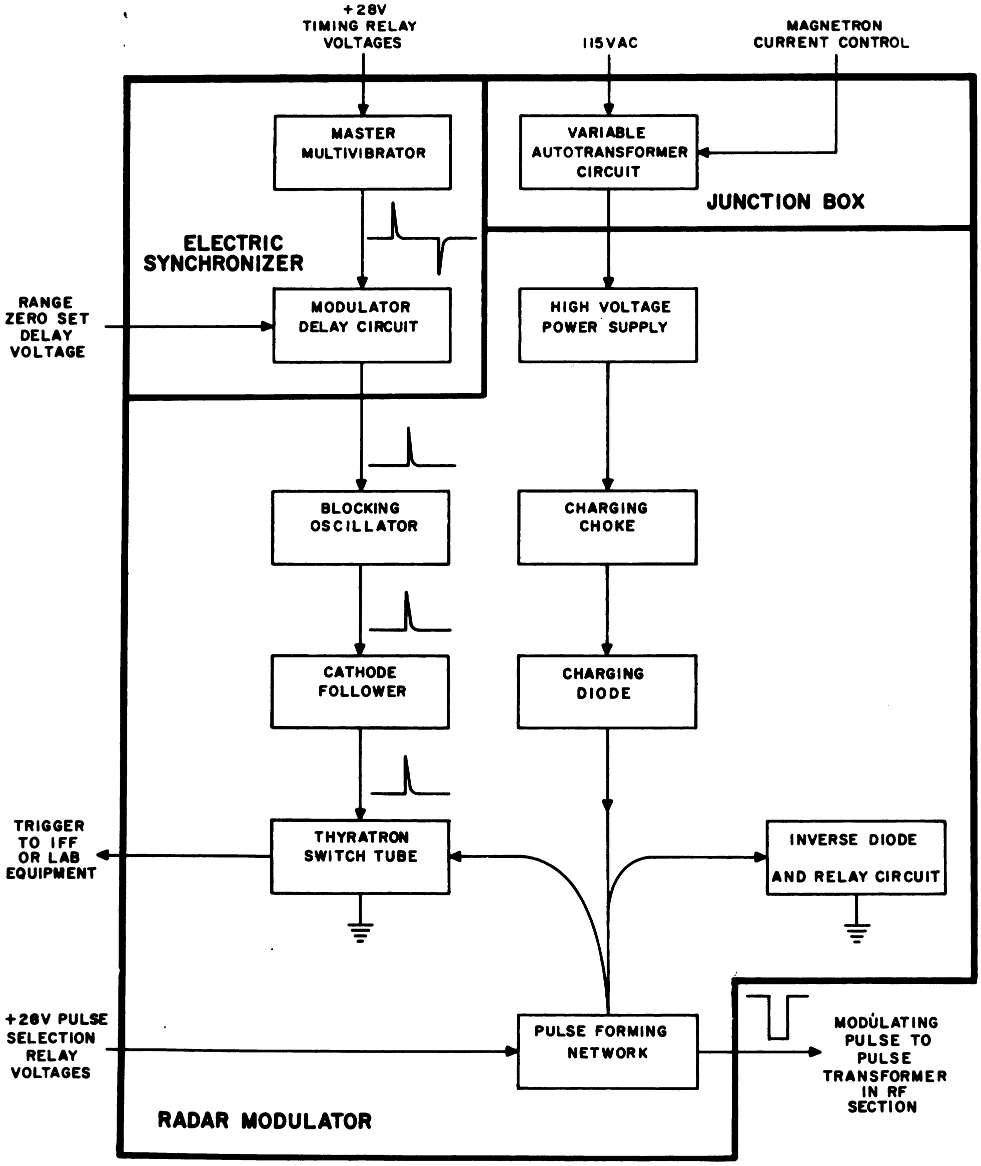
+28V TIMING RELAY VOLTAGES
115VAC
MAGNETRON CURRENT CONTROL
MASTER MULTIVIBRATOR
VARIABLE AUTOTRANSFORMER CIRCUIT
JUNCTION BOX
ELECTRIC SYNCHRONIZER
RANGE ZERO SET DELAY VOLTAGE
MODULATOR DELAY CIRCUIT
HIGH VOLTAGE POWER SUPPLY
BLOCKING OSCILLATOR
CHARGING CHOKE
CATHODE FOLLOWER
CHARGING DIODE
TRIGGER TO IFF OR LAB EQUIPMENT
THYRATRON SWITCH TUBE
INVERSE DIODE AND RELAY CIRCUIT
+28V PULSE SELECTION RELAY VOLTAGES
PULSE FORMING NETWORK
MODULATING PULSE TO PULSE TRANSFORMER IN RF SECTION
RADAR MODULATOR

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Figure 15-11. –Transmitting function timing and modulation sections, block diagrams.

to the feedhorn and reflector and is radiated into space.

When the magnetron's output pulse is directed to the dummy load, it is fed through a directional coupler which extracts a sample from the pulse. The major portion of the output pulse is absorbed by the dummy load, which converts the RF energy into heat and radiates the heat into the surrounding air. The RF sample from the direction coupler is fed to both the tuned cavity and to the RF test signal circuits.

The tuned cavity is an echo box which is resonant at two selected frequencies. It should be noted that the tuned cavity may be energized by either directional coupler. When the magnetron is tuned to either of these two frequencies, the energy will cause the cavity to ring.

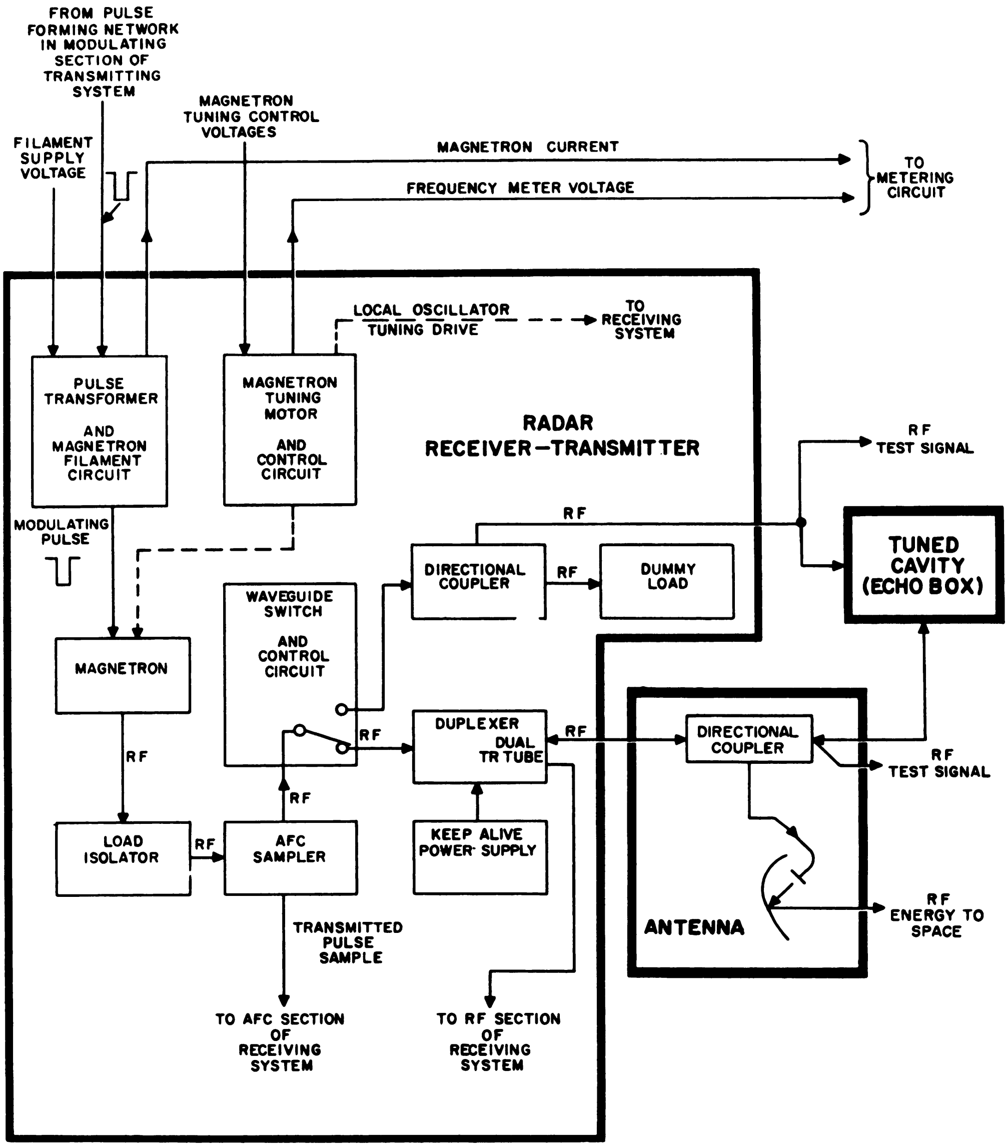

Figure 15-12.—Transmitting function RF and tuning section, block diagram.

The ringing signal, which is present for a time after each transmitter pulse, is fed through the directional coupler in the path to the antenna and through the duplexer to the receiving circuits. After being amplified by the receiver and fed to the indicator, the indicator displays these ringing signals, thus providing a means of quickly checking the transmitting and receiving channels. This check is especially useful when the dummy load is used or when no target returns are available.

The master trigger circuits and the modulator delay circuits are located in the electrical synchronizer (5, fig. 15-1). The trigger amplifier, thyratron switch, high-voltage supply, charging circuit, and the pulse-forming network are lcoated in the radar modulator (6, fig. 15-1). The variable autotransformer is located in the junction box. The RF circuits are located in the radar receiver-transmitter (2, fig. 15-1). However, all controls for these circuits are located on the bomb director control.

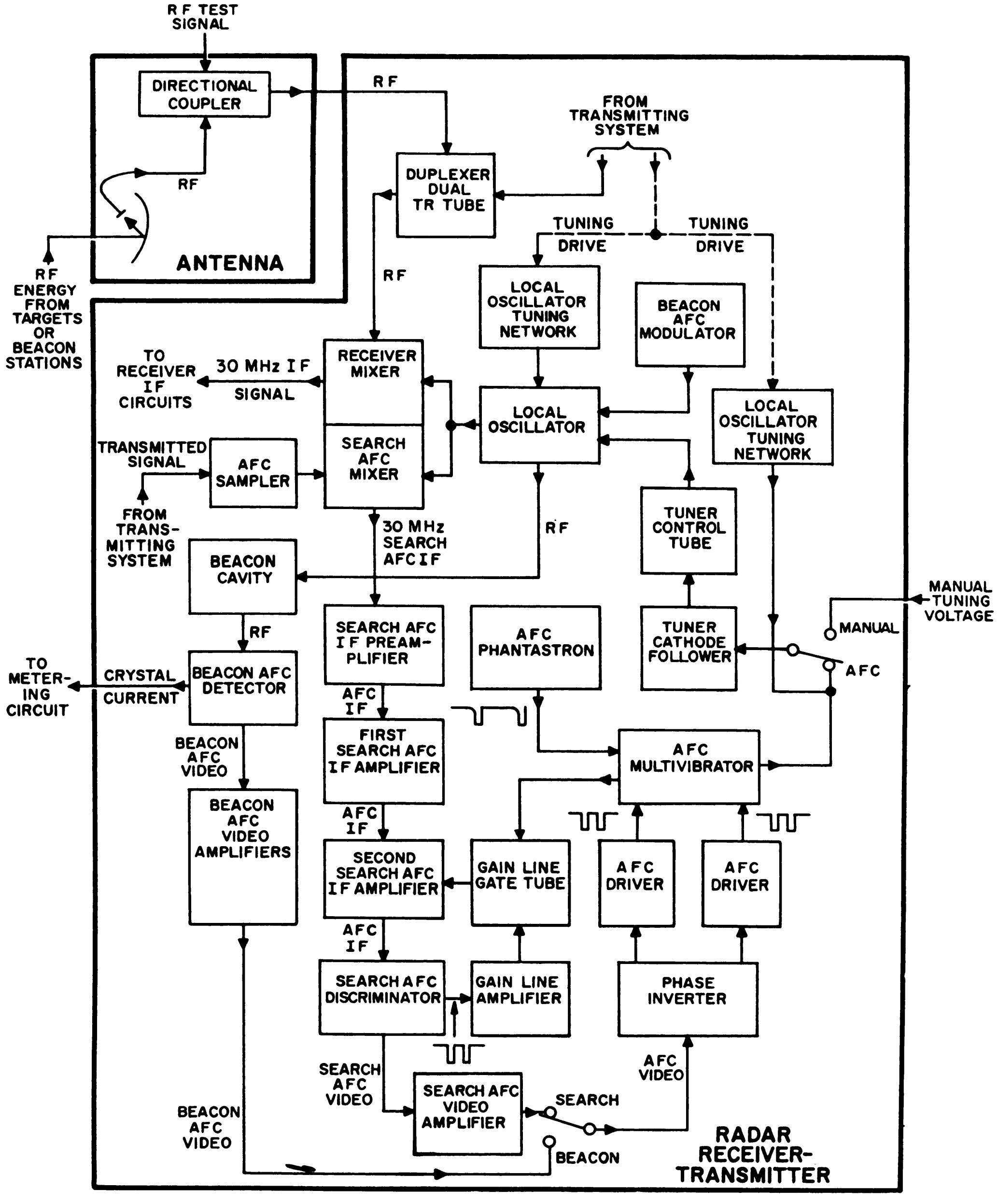

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Figure 15-13.–Receiving system, RF and AFC section, block diagram.

Receiving Function

The receiving channel of the radar system is illustrated by block diagram in figure 15-13 and 15-14 and should be referred to during the discussion that follows.

The RF echo signals, or the beacon response signals, are received by the antenna and fed through the directional coupler and the duplexer to the receiver mixer. The signal from the local oscillator is also applied to the receiver mixer, which produces the IF pulses. (NOTE: The directional coupler provides a means of inserting an RF test signal or the ringing signal into the waveguide as previously described.)

Referring to figure 15-14, note that the IF pulses are first amplified by the IF preamplifiers and then further amplified by the IF

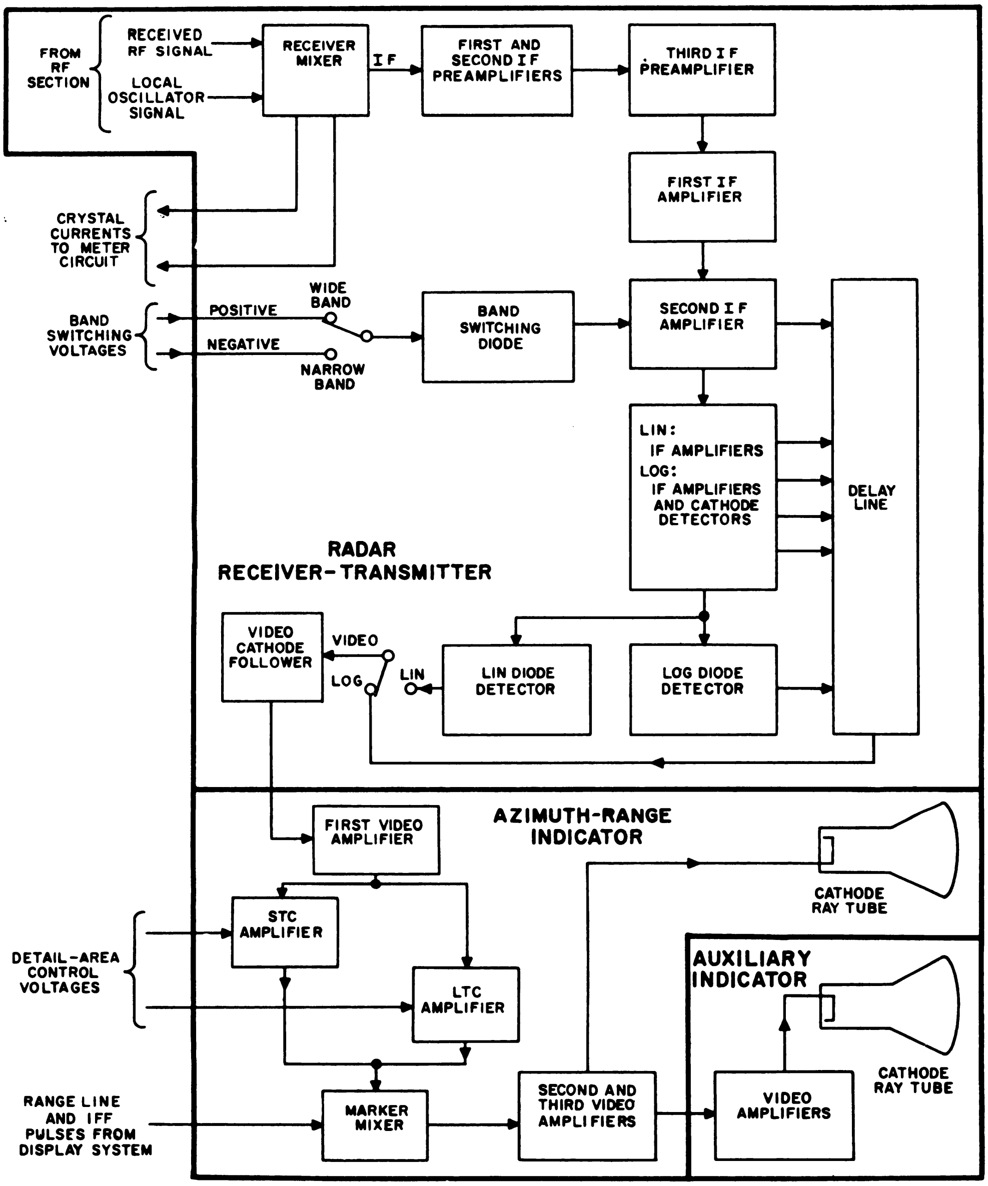

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Figure 15-14. —Receiving system, IF and video sections, block diagram.

amplifiers before being detected by one of the detectors. The output of the detector, a series of video pulses, is amplified and fed to the marker mixer circuit where it is combined with range line and other marker pulses.

During search operation, the search AFC circuit functions to control the local oscillator's frequency thereby producing the correct intermediate frequency regardless of any shift in transmitter frequency. To accomplish this, a small sample of the magnetron's output signal, which is of the same frequency as the received signal, is combined with the local oscillator's output in the search AFC mixer. The output of the mixer is a series of pulses of a frequency which is equal to the difference between the two input signals.

The search AFC intermediate frequency signal is amplified by the search AFC intermediate frequency preamplifiers and amplifiers and fed to the descriminator. As in the AFC circuit, discussed in chapter 9 of this course, the output of the discriminator is of an amplitude and polarity to produce the necessary change in the output of the local oscillator.

During beacon operation, the beacon AFC modulator generates a waveform which frequency modulates the local oscillator. In order for the receiver mixer to produce the intermediate frequency during beacon operation, the local oscillator must operate at a center frequency which is below the beacon response signal an amount equal to the intermediate frequency of the receiver. The frequency-modulated local-oscillator signal is fed through the beacon cavity to the beacon AFC detector. The cavity and the detector operate in conjunction with each other to produce beacon AFC video pulses when the center frequency of the local oscillator is close to, but not exactly equal to, the beacon response signal minus the specified intermediate frequency. The polarity of the beacon AFC pulses depends upon the direction of the deviation of the center frequency (or the direction of the drift of the intermediate frequency). When the local-oscillator center frequency is correct, there is no output from the beacon AFC detector. If not correct, the beacon AFC video pulses from the detector are amplified by the beacon AFC video amplifiers, and then applied to the AFC control and local-oscillator tuning circuits.

When the local oscillator operates at a frequency which is much different from that required to produce the specified IF, there are no AFC video pulses during either search or beacon operation. This is usually the case when the equipment is first turned on. The AFC and local-oscillator tuning circuits then cause the local-oscillator frequency to be swept over a wide range until AFC video pulses are produced, after which time the AFC and local-oscillator tuning circuits respond to the AFC video pulses and shift the local-oscillator frequency to that required. Then, whenever the intermediate frequency drifts, AFC video pulses become available. The AFC and local-oscillator tuning circuits respond to these pulses and return the frequency of the local oscillator to that required for producing and maintaining the required intermediate frequency.

Whenever the magnetron is tuned by the magnetron tuning mechanism, this mechanism also drives potentiometers in the AFC and local-oscillator tuning circuits, and causes these circuits to change the local oscillator frequency by the same amount as the magnetron frequency is changed. Provisions are also made for manually tuning the local oscillator, even though the magnetron is not being tuned.

Display Function

The display function of the tunable radar in the bomb director set is divided into the following four sections:

1. The timing section, which generates the synchronizing and time delay pulses.
2. The sweep section, which generates the necessary sweep waveforms to produce and position the indicator traces.
3. The precision section, which permits the radar to use the precision altitude and range data computed by the bombing data computer.
4. The marker section, which produces the various marker pulses for the presentations.

Referring to figure 15-15, the display channel timing section block diagram, the master trigger blocking oscillator circuit generates both positive and negative master trigger pulses. The positive master trigger output is applied to the H (precision altitude) circuits. The negative master trigger output is fed to the sweep delay circuits, the altitude delay circuits, and the sweep circuits.

The sweep delay circuits produce a pulse which is delayed with respect to the negative master trigger by an amount determined by the bombing data computer. When the expanded B-type presentation is used at short ranges, the delay voltage is proprotional to the computed slant range minus a set fraction of the computed horizontal range. To this value is added a sweep delay set voltage which is adjusted to equal the delay of the modulator trigger. When the modified B-type presentation is used at long ranges, the delay voltage is proportional to the computed horizontal range minus a fixed delay. To this value is added the sweep delay set voltage.

A negative output pulse from the sweep delay circuits is fed to the fixed delay on long ranges, and is made available to the sweep circuits as the sweep delay trigger. The fixed delay circuits generate a pulse which is delayed with respect to the output pulse of the sweep delay circuits by an amount equivalent to the fixed delay range. This pulse is used as the search range line pulse.

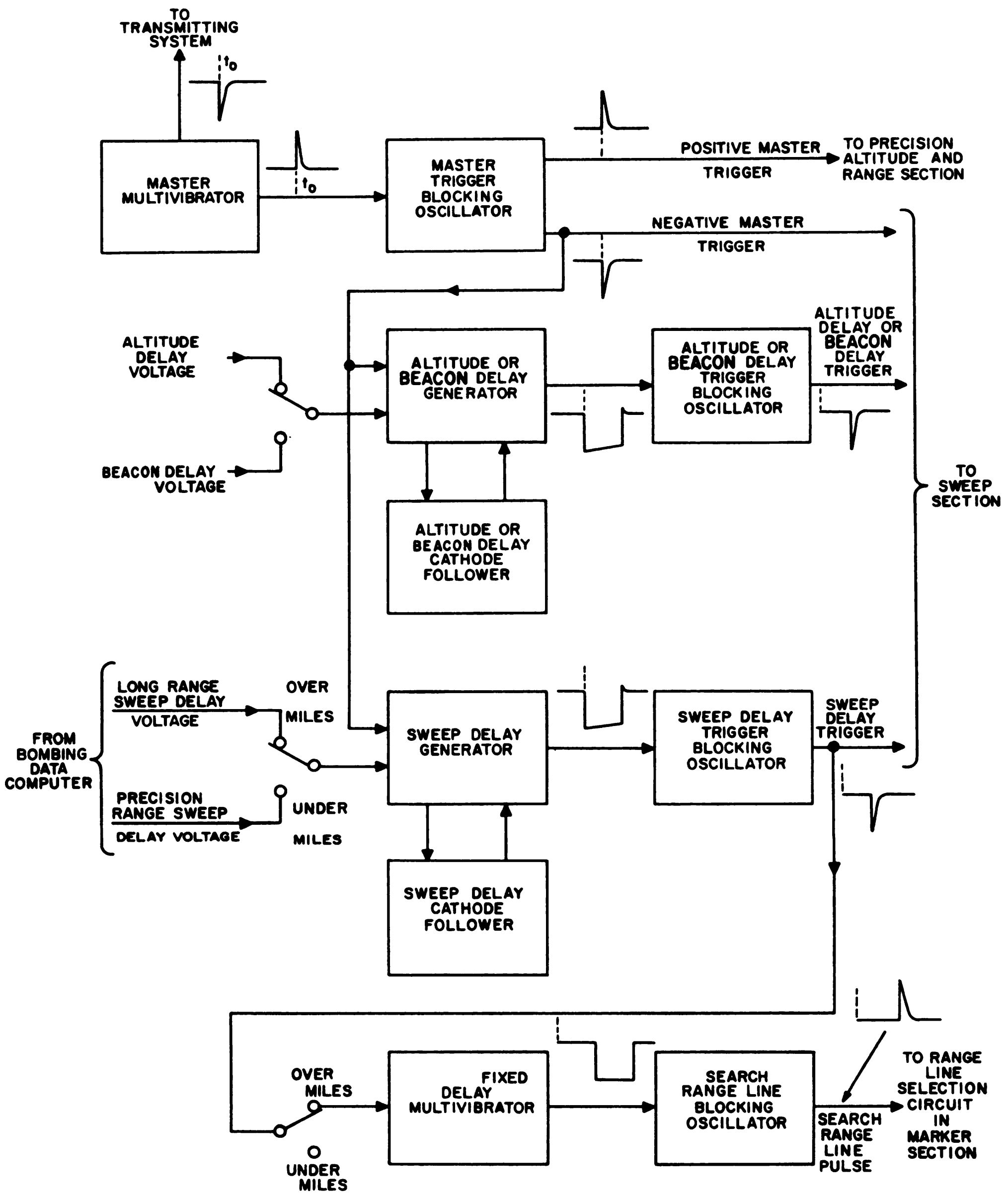
TO TRANSMITTING SYSTEM
t_0
MASTER MULTIVIBRATOR
t_0
MASTER TRIGGER BLOCKING OSCILLATOR
POSITIVE MASTER TRIGGER
TO PRECISION ALTITUDE AND RANGE SECTION
NEGATIVE MASTER TRIGGER
ALTITUDE DELAY VOLTAGE
BEACON DELAY VOLTAGE
ALTITUDE OR BEACON DELAY GENERATOR
ALTITUDE OR BEACON DELAY TRIGGER BLOCKING OSCILLATOR
ALTITUDE DELAY OR BEACON DELAY TRIGGER
ALTITUDE OR BEACON DELAY CATHODE FOLLOWER
TO SWEEP SECTION
FROM BOMBING DATA COMPUTER
LONG RANGE SWEEP DELAY VOLTAGE
OVER MILES
PRECISION RANGE SWEEP DELAY VOLTAGE
UNDER MILES
SWEEP DELAY GENERATOR
SWEEP DELAY TRIGGER BLOCKING OSCILLATOR
SWEEP DELAY TRIGGER
SWEEP DELAY CATHODE FOLLOWER
OVER MILES
UNDER MILES
FIXED DELAY MULTIVIBRATOR
SEARCH RANGE LINE BLOCKING OSCILLATOR
SEARCH RANGE LINE PULSE
TO RANGE LINE SELECTION CIRCUIT IN MARKER SECTION

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Figure 15-15.—Display function timing section.

When the equipment is used for short range search, the altitude or beacon delay circuits produce a pulse that is delayed, with respect to the master trigger, by an amount equivalent to the aircraft's altitude, or by an amount equivalent to the beacon delay when the equipment is used for beacon location on the beacon long range operation. The pulse from the altitude or beacon delay circuits is made available to the sweep circuits as a trigger.

The following is a summary of the different triggers available to the sweep circuits, and a description of the conditions under which each is used. The negative master trigger direct from the master trigger circuits is used for all PPI presentations during either search or beacon operation, except when a delayed sweep is desired. The altitude delay trigger from the altitude or beacon delay circuits can be selected for any short range operation when it is desirable to delay the start of the PPI sweep by an amount corresponding to the altitude of the aircraft, and thus eliminate the altitute "hole" near the starting point of the sweep traces. The beacon delay trigger is selected for beacon operation when the long range beacon operation is used. This delay moves distant beacon returns, which normally would appear near the edge of the indicator screen, nearer the center of the screen for better definition. The sweep delay trigger is selected when expanded presentations are used. The amount of sweep delay normally used on short range operations is dependent upon the radar slant range and computed horizontal range plus the sweep delay set. When the equipment is operating on long range, the delay is normally determined by the computed horizontal range and the fixed delay plus the sweep delay set. The precision altitude trigger from the H circuits, which have not yet been discussed, is used for the zero-set, altitute-set, and echo-test presentations. This will be discussed later with the precision altitude and precision range circuits.

The SWEEP SECTION produces the basic sweep waveform for each type of presentation. During PPI operation, this waveform of variable length is amplified and fed to the sweep resolver which is located on the antenna. The sweep resolver produces the horizontal and vertical PPI sweeps for the deflection coils in the indicator.

The sweep circuits and the sweep resolver also perform the same functions when an expanded presentation at long range is used. The sweep waveform for this type of presentation is always a fixed length. Since resolved sweeps are used for the expanded presentation at long range, it may at first appear that this presentation is of the PPI type. Actually, it is a combination PPI-and B-type presentation, because azimuth expantion is used as well as sweep expansion. The azimuth expansion will be discussed in the following section.

When the expanded B-type presentation is used at short ranges or for calibration purposes, the sweep waveform from the sweep section is fed directly to the vertical deflection coils as the fast vertical sweep, or the precision range sweep as it is sometimes called. The sweep resolver and the horizontal deflection coil are not used at that time. For the expanded presentation, which is used at short ranges, the sweep is expanded by an amount inversely proportional to the range. This means that the expansion is continuously increased as the range decreases. To provide this varying expansion, the bombing data computer supplies the sweep circuits with a variable sweep charging voltage proportional to the computed horizontal range. This sweep changing voltage, called the automatic range expansion voltage, keeps the sweep duration proportional to the computed horizontal range. When an aimpoint is being tracked, this voltage is automatically switched to the sweep circuits at the time the decreasing computed range becomes equal to short range operation. The purpose of the varying range coverage is to keep the range scale of the presentation equal to the azimuth scale.

The DEPRESSED CENTER and the AZIMUTH EXPANSION SECTION are illustrated in figure 15-16. The depressed center circuit supplies a depression current to a separate depressed center coil in the deflection coil assembly. This coil positions the sweep traces so that they start near the bottom of the indicator.

The 5,000 hertz oscillator (fig. 15-16) generates a 5,000 hertz reference voltage for the azimuth expansion circuits, and a 5,000 hertz excitation voltage for the expansion synchro transmitter on the antenna. The rotation of this synchro shaft represents the reflector scan angle (ω_R). The synchro converts this rotation into 5,000-hertz azimuth expansion synchro data, and supplies it to the azimuth expansion circuits, the azimuth line circuits, and the bombing data computer.

The azimuth expansion circuits produce expansion currents of a value proportional to the reflector scan angle, and of a direction determined by whether this angle is to the right or to the left of the direction indicated by the azimuth line. The expansion currents are fed through the two expansion coils in the deflection coil assembly. The currents through these coils position the sweep traces horizontally (in azimuth) across the indicator screen as the antenna scans. This positioning provides all of the horizontal deflection for the conventional B-type presentation.

It should be remembered that the modified B-type presentation used at long ranges is a combination PPI- and B-type presentation. Without azimuth expansion, the sweep traces would all start at the same point on the indicator screen and a PPI presentation expanded only in range would be obtained. The azimuth expansion modifies such a presentation by spreading the display horizontally on the screen.

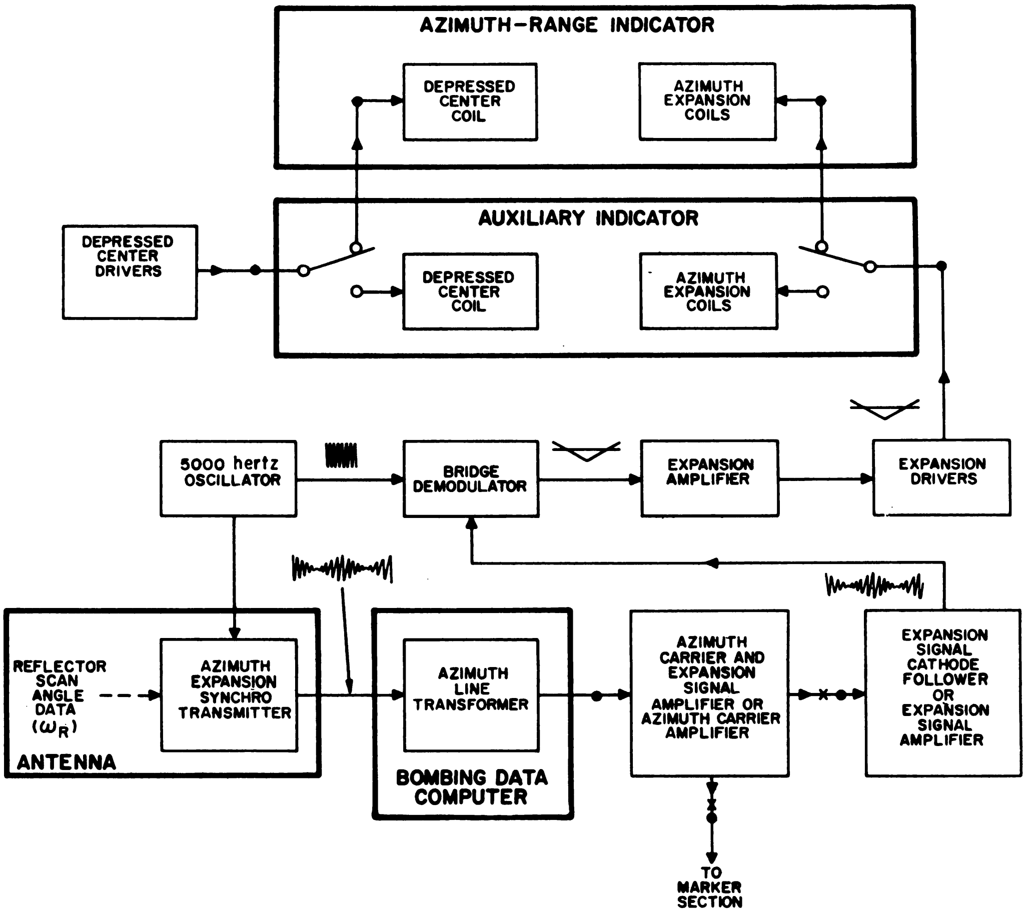

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Figure 15-16.—Depressed center and azimuth expansion section, block diagram.

This presentation still retains a wedge shape, because of the action of the sweep resolver, but each sweep trace, like a B-type presentation, has a different starting point because of the azimuth expansion. The deflection of the expansion coils is actually superimposed upon the deflection of both the horizontal and vertical deflection coils. When a PPI presentation is selected, the azimuth expansion circuits are disabled.

The H (altitude) and r - H (slant range-altitude) section is illustrated in block diagram form in figure 15-17. The H and r - H circuits are used for producing the precision altitude trigger and the precision range line pulse. The precision altitude trigger is used by the sweep circuits when the altitude-set, zero-set, and echo-test presentations are used. The precision range line pulse produces the range line for these presentations and for all of the other presentations when the computed horizontal range is under a preset value (short range operation).

The positive master trigger from the master trigger circuits triggers the H circuits, which develop the precision altitude trigger and a trigger for the r - H circuits. These outputs are delayed with respect to the master trigger by an amount equivalent to a delay voltage from the bombing data computer. This delay voltage is either the altitude calibrate (H cal) delay voltage, the ring time plus the altitude calibrate delay voltage, or the precision altitude (H) plus the altitude calibrate (H cal) delay voltage. The H voltage is called the precision altitude voltage because it is a precise function of the altitude. The H cal voltage, which is a fixed d-c delay voltage, is selected as the delay voltage for the zero set presentation. The ring time plus H cal voltage is selected for the

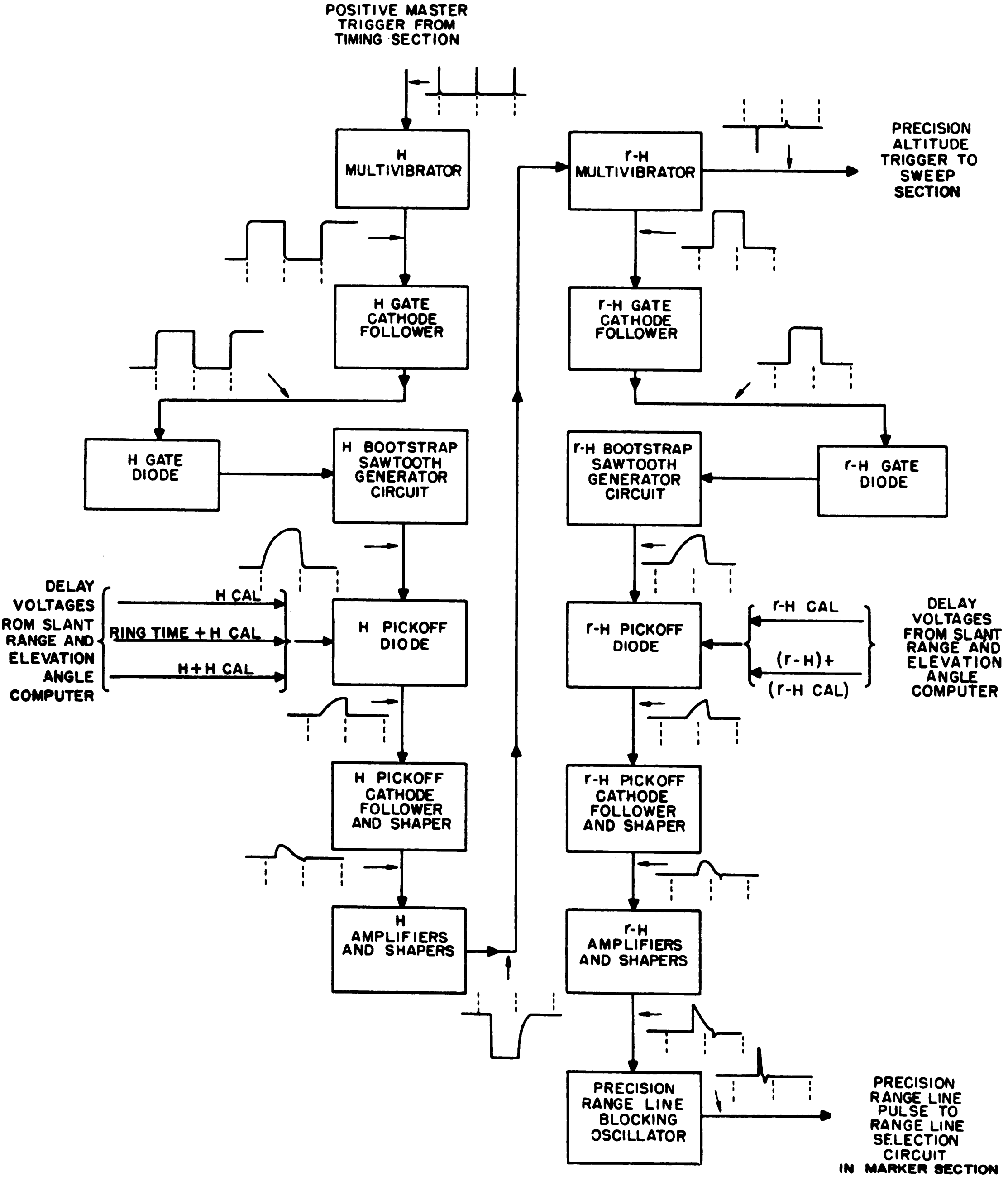
POSITIVE MASTER TRIGGER FROM TIMING SECTION
H MULTIVIBRATOR
r-H MULTIVIBRATOR
PRECISION ALTITUDE TRIGGER TO SWEEP SECTION
H GATE CATHODE FOLLOWER
r-H GATE CATHODE FOLLOWER
H GATE DIODE
H BOOTSTRAP SAWTOOTH GENERATOR CIRCUIT
r-H BOOTSTRAP SAWTOOTH GENERATOR CIRCUIT
r-H GATE DIODE
DELAY VOLTAGES FROM SLANT RANGE AND ELEVATION ANGLE COMPUTER
H CAL
RING TIME + H CAL
H+H CAL
H PICKOFF DIODE
r-H PICKOFF DIODE
r-H CAL
(r-H)+
(r-H CAL)
DELAY VOLTAGES FROM SLANT RANGE AND ELEVATION ANGLE COMPUTER
H PICKOFF CATHODE FOLLOWER AND SHAPER
r-H PICKOFF CATHODE FOLLOWER AND SHAPER
H AMPLIFIERS AND SHAPERS
r-H AMPLIFIERS AND SHAPERS
PRECISION RANGE LINE BLOCKING OSCILLATOR
PRECISION RANGE LINE PULSE TO RANGE LINE SELECTION CIRCUIT IN MARKER SECTION

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Figure 15-17.—Precision altitude and range section.

echo-test presentation, and the H + H cal voltage is used at all other times.

Another delay voltage from the bombing data computer is applied to the r - H circuits. This delay voltage is one of the following:

1. Slant range minus altitude calibrate (r - H cal) delay voltage.
2. Slant range minus altitude (r - H) delay voltage.

3. Slant range minus altitude (r - H) delay voltage plus slant range minus altitude calibrate (r - H cal) delay voltage.

The r - H voltage is a precise function of the slant range minus the altitude and the r - H cal voltage is a fixed delay voltage. The r - H cal voltage is selected as the delay for the zero-set, altitude-set, and echo-test presentation, and the (r - H) + (r - H cal) voltage is used at other times. The r - H circuits produce the precision range-line pulse, which is used during calibration and the echo test, and whenever the short range operation is used. This pulse is delayed with respect to the master trigger by an amount equal to the sum of two delays introduced by the bombing data computer.

A summary of the different delays used for the precision range-line pulse under different operating condidtions follows:

1. For the zero-set presentation, the delay is equal to H cal + (r - H cal). Their sum, r, represents the computed zero slant range. To make the calibration, the modulator trigger is delayed at the modulator delay circuit an amount which makes the transmitter pulse coincide in time with the precision range-line pulse. This calibration makes the computed zero range and the actual zero range equal to each other.

2. For the altitude-set presentation, the delay of the precision range-line pulse is equal to (H + H cal) + (r - H cal). Since H cal + (r - H cal) represents both the computed and actual zero slant range, the total delay with respect to zero range is H, representing the computed altitude. To make the altitude-set calibration, the necessary correction is first introduced to make the computed altitude equal to the actual altitude. Then, with these quantities equal, the H information is used to calibrate the altitude and vertical velocity meter in the bombing data computer.

3. For the echo-test presentation, the delay of the precision range-line pulse is equal to (ring time + H cal) + (r - H cal). Since H cal + (r - H cal) represents both the computed and actual zero slant range, the total delay with respect to zero range is ring time, which is adjustable by means of a calibrated control on the bomb director control. When the echo-test presentation is used, the magnetron is tuned to the resonant frequency of the tuned cavity (echo box), causing the tuned cavity to ring. The received ringing signal is displayed on the indicator. The ring-time delay is adjusted until the end of the ringing signal coincides in time with the precision range line. The control setting then indicates the measured ring time. The length of the ring time depends upon the transmitter power output and the receiver sensitivity. Therefore, the ring-time measurement is a check of the overall operation of the transmitting and receiving sections.

4. During search or beacon operation at short ranges, the delay of the precision range-line pulse is equal to (H + H cal) + [(r - H) + (r - H cal)]. Since H cal + (r - H cal) represents the delay of the transmitter pulse with respect to the master trigger, H + (r - H), or r, represents the delay of the precision range line with respect to zero range. This delay corresponds to the computed slant range of the aim point.

When the PPI presentation is used at short ranges, the r - H voltage may be varied by the operator to produce any desired amount of delay of the precision range-line pulse.

The AZIMUTH LINE and COURSE MARKER SECTION are illustrated in figure 15-18. The azimuth line circuits amplify and detect the modulated 5,000-hertz waveform from the azimuth expansion synchro transmitter, and use the detected waveform as a gate for admitting the intensity gate pulses from the sweep circuits when the reflector scan angle is 0°. The selected intensity gate pulses are used to form azimuth line trigger pulses for the azimuth and course marker circuits.

The bombing data computer uses the azimuth expansion synchro data in developing the relative course (η_R) signal for the course marker circuits. The η_R signal is also a modulaed 5,000 hertz signal, the null of which occurs when the antenna scans past the direction of the aircraft's course. (The course of the aircraft is the direction the aircraft is actually traveling over the ground.) The course marker circuits amplify and detect the η_R waveform and use the detected voltage as a gate for admitting the tips of sawtooth pulses. These sawtooth pulses are produced from the sweep feedback waveform supplied by the sweep circuits. The selected tips of the sawtooth pulses are used to form the course marker trigger pulses for the azimuth and course marker circuits.

The azimuth and course marker circuits generate an azimuth line pulse for each azimuth line trigger received, and a course marker pulse for each course marker trigger received. The intensity gate from the sweep circuits is fed to the intensity gate cathode follower. Its

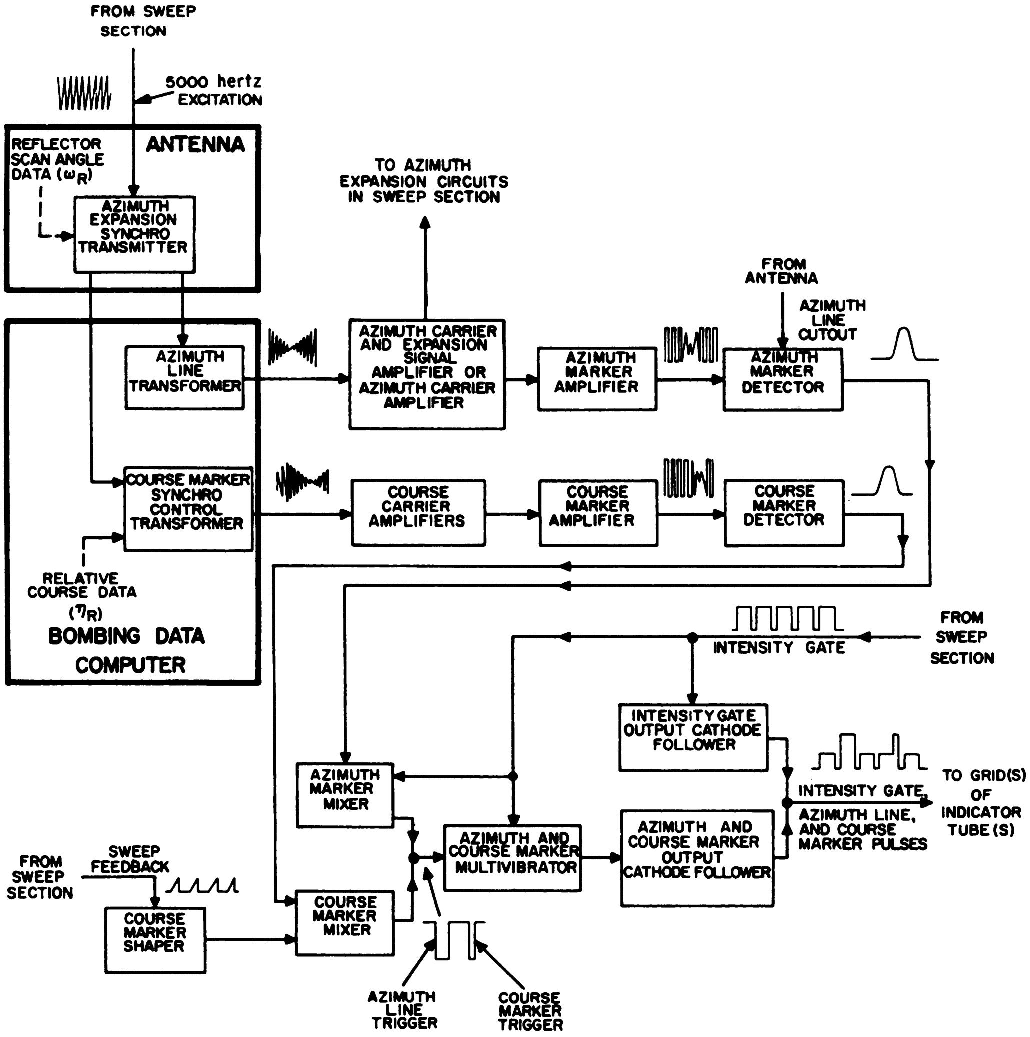
FROM SWEEP SECTION
5000 hertz EXCITATION
REFLECTOR SCAN ANGLE DATA (ω_R)
ANTENNA
AZIMUTH EXPANSION SYNCHRO TRANSMITTER
TO AZIMUTH EXPANSION CIRCUITS IN SWEEP SECTION
AZIMUTH LINE TRANSFORMER
AZIMUTH CARRIER AND EXPANSION SIGNAL AMPLIFIER OR AZIMUTH CARRIER AMPLIFIER
AZIMUTH MARKER AMPLIFIER
FROM ANTENNA
AZIMUTH LINE CUTOUT
AZIMUTH MARKER DETECTOR
COURSE MARKER SYNCHRO CONTROL TRANSFORMER
COURSE CARRIER AMPLIFIERS
COURSE MARKER AMPLIFIER
COURSE MARKER DETECTOR
RELATIVE COURSE DATA (η_R)
BOMBING DATA COMPUTER
INTENSITY GATE
FROM SWEEP SECTION
INTENSITY GATE OUTPUT CATHODE FOLLOWER
AZIMUTH MARKER MIXER
INTENSITY GATE, AZIMUTH LINE, AND COURSE MARKER PULSES
TO GRID(S) OF INDICATOR TUBE(S)
AZIMUTH AND COURSE MARKER MULTIVIBRATOR
AZIMUTH AND COURSE MARKER OUTPUT CATHODE FOLLOWER
FROM SWEEP SECTION
SWEEP FEEDBACK
COURSE MARKER SHAPER
COURSE MARKER MIXER
AZIMUTH LINE TRIGGER
COURSE MARKER TRIGGER

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Figure 15-18.–Marker sections.

output is combined with the output from the azimuth and course marker output cathode follower. The combined pulses are fed to the intensity (control) grid of the cathode-ray tube. These positive pulses cause the sweep traces to be visible on the screen of the CRT. The azimuth line pulses brighten one or more sweep traces when the reflector scan angle is 0°. (The scan angle is 0° when the antenna scans through the line of sight to the aim point or another selected target.) Therefore, the sweep, when brightened by the azimuth line pulses, is called the AZIMUTH LINE. The course marker pulses brighten the end of one or more sweep traces when the antenna scans through the direction of the aircraft's course thereby forming the course marker at the outer edge of the sweep on the CRT screen.

Antenna Stabilizing and Scanning Functions

The circuits and mechanism used to stabilize and drive the antenna reflector are illustrated in figure 15-19 through 15-22. The stabilizing system of the antenna consists of the roll, pitch, and azimuth servo loops, and also the azimuth platform during narrow-degree scanning operation. During wide-degree scanning operation, the azimuth platform is used as the scanning system. The narrow-degree scanning system consists of the narrow-degree

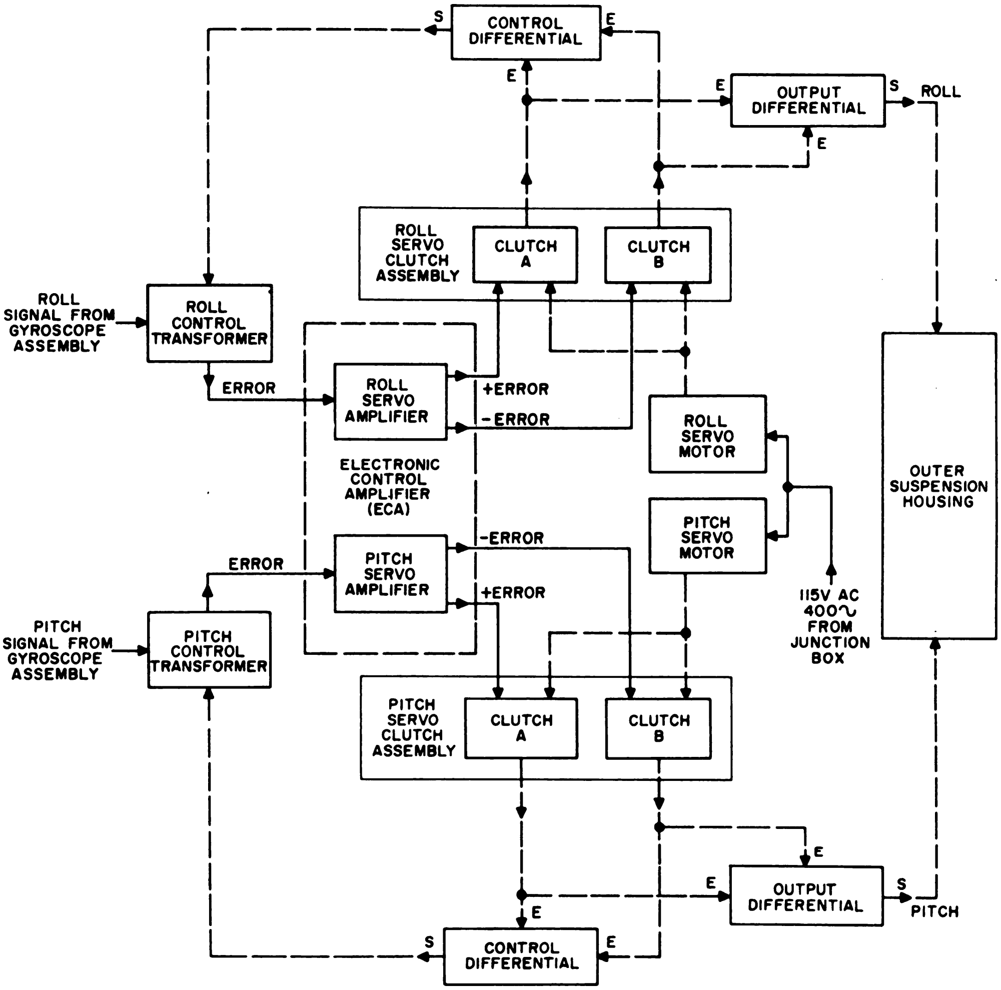
CONTROL DIFFERENTIAL
S
E
E
OUTPUT DIFFERENTIAL
ROLL
ROLL SERVO CLUTCH ASSEMBLY
CLUTCH A
CLUTCH B
ROLL SIGNAL FROM GYROSCOPE ASSEMBLY
ROLL CONTROL TRANSFORMER
ERROR
ROLL SERVO AMPLIFIER
+ERROR
-ERROR
ROLL SERVO MOTOR
OUTER SUSPENSION HOUSING
ELECTRONIC CONTROL AMPLIFIER (ECA)
PITCH SERVO MOTOR
PITCH SERVO AMPLIFIER
115V AC 400∿ FROM JUNCTION BOX
PITCH SIGNAL FROM GYROSCOPE ASSEMBLY
PITCH CONTROL TRANSFORMER
PITCH SERVO CLUTCH ASSEMBLY
PITCH

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Figure 15-19.—Antenna roll and pitch stabilization servo system, block diagram.

scan drive motor and clutch, and the inertia compensator.

The roll and pitch servo loops (fig. 15-19) receive roll and pitch synchro data supplied by the gyroscope assembly. These servo loops use this data to stabilize the feedhorn and reflector in roll and pitch to prevent the rolling and pitching movements of the aircraft from moving the feedhorn and reflector. Roll and pitch corrections are made through the antenna outer column, the azimuth platform, and the antenna inner column to which the feedhorn and reflector are attached. The inner and outer columns are maintained vertical at all times, unless the deviation from level flight is greater than the correcting capabilities of the stabilizing system.

The azimuth servo loop (fig. 15-20) receives relative-bearing (θ_R) data from a synchro transmitter in the bombing data computer. During narrow degree scanning operation, this servo loop feeds θ_R, information to the azimuth platform. Another servo loop of the platform uses this information for azimuth stabilization of (1) the platform, (2) the inner column, (3) the inertia compensator, (4) the feedhorn, and (5) the reflector.

Azimuth stabilization in this sense is actually relative bearing stabilization; that is,

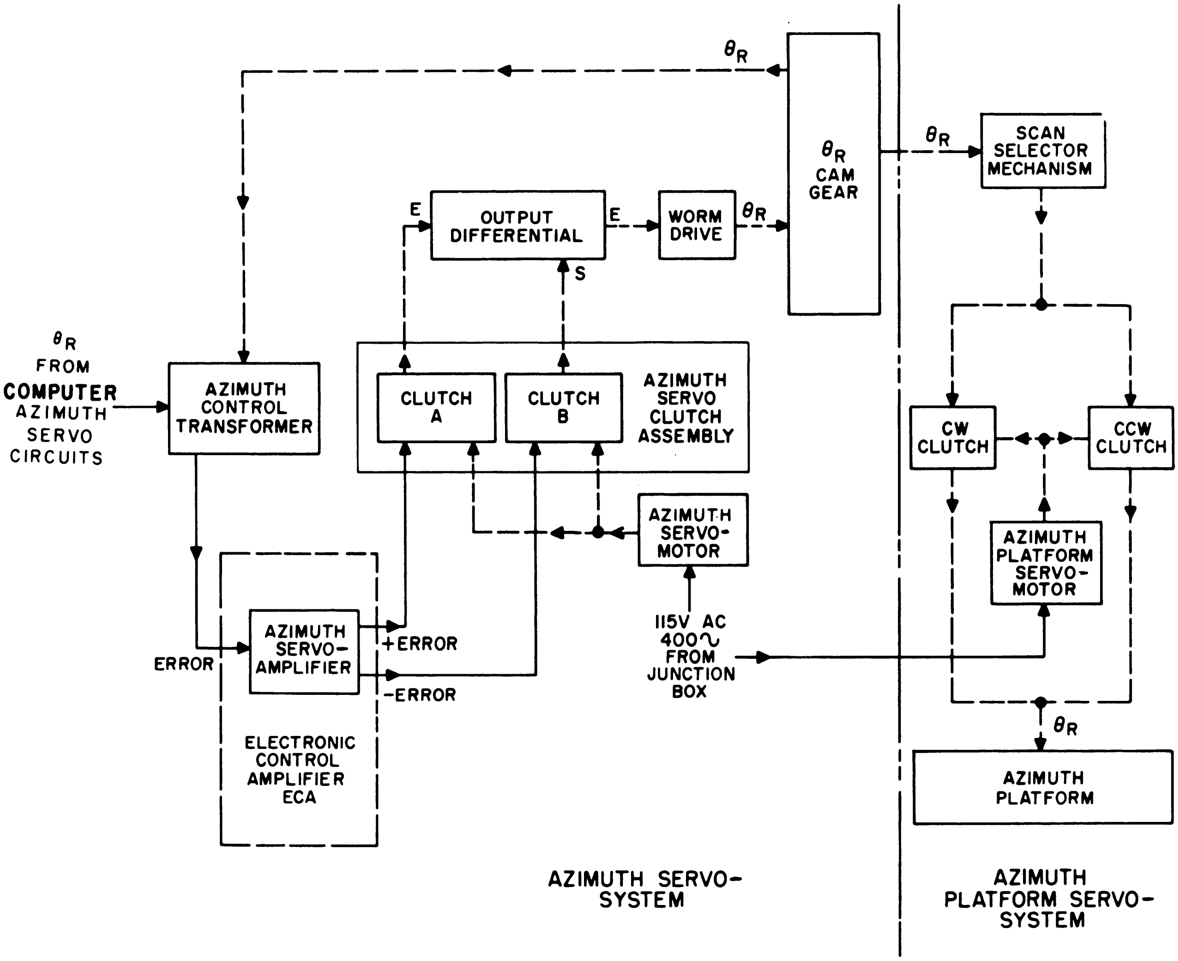
θR
θR CAM GEAR
θR
SCAN SELECTOR MECHANISM
E
OUTPUT DIFFERENTIAL
E
WORM DRIVE
θR
S
θR FROM COMPUTER AZIMUTH SERVO CIRCUITS
AZIMUTH CONTROL TRANSFORMER
CLUTCH A
CLUTCH B
AZIMUTH SERVO CLUTCH ASSEMBLY
CW CLUTCH
CCW CLUTCH
AZIMUTH SERVO-MOTOR
AZIMUTH PLATFORM SERVO-MOTOR
ERROR
AZIMUTH SERVO-AMPLIFIER
+ERROR
-ERROR
115V AC 400∿ FROM JUNCTION BOX
θR
AZIMUTH PLATFORM
ELECTRONIC CONTROL AMPLIFIER ECA
AZIMUTH SERVO-SYSTEM
AZIMUTH PLATFORM SERVO-SYSTEM

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Figure 15-20. –Antenna azimuth and azimuth platform stabilization servo system, block diagram.

for any given value of θ_R, the center of the sector which the antenna scans is kept fixed in its direction. However, when the relative bearing changes because of either the movements of the aircraft or the selection of a different aim point, the θ_R corrections, which are introduced manually by the operator or automatically by the bombing data computer, cause the azimuth servo loop to supply a different value of θ_R to the azimuth platform. The platform then drives the inner column, the feedhorn, and the reflector, so that the antenna always scans the sector whose center is established by the value of θ_R. During wide-degree scanning operation, the feedhorn and reflector are not stabilized in azimuth.

Figure 15-21 is a block diagram of the scan selector and the narrow-degree scanning systems. The blocks marked with an asterisk represent the scan selector system, and the remainder of the blocks represent the narrow-degree scanning system.

When the function switch is placed in any position except wide scan search, the narrow-degree slow scan solenoid is energized. The action of the solenoid controls the scan selector switch S4 which applies power to the scan selector motor. The scan selector motor drives the cam mechanism in the azimuth platform, and it also actuates the scan selector switch S5 which provides a ground for the circuit through the narrow scan direction switch.

The narrow scan drive motor is energized when the director function switch is placed in

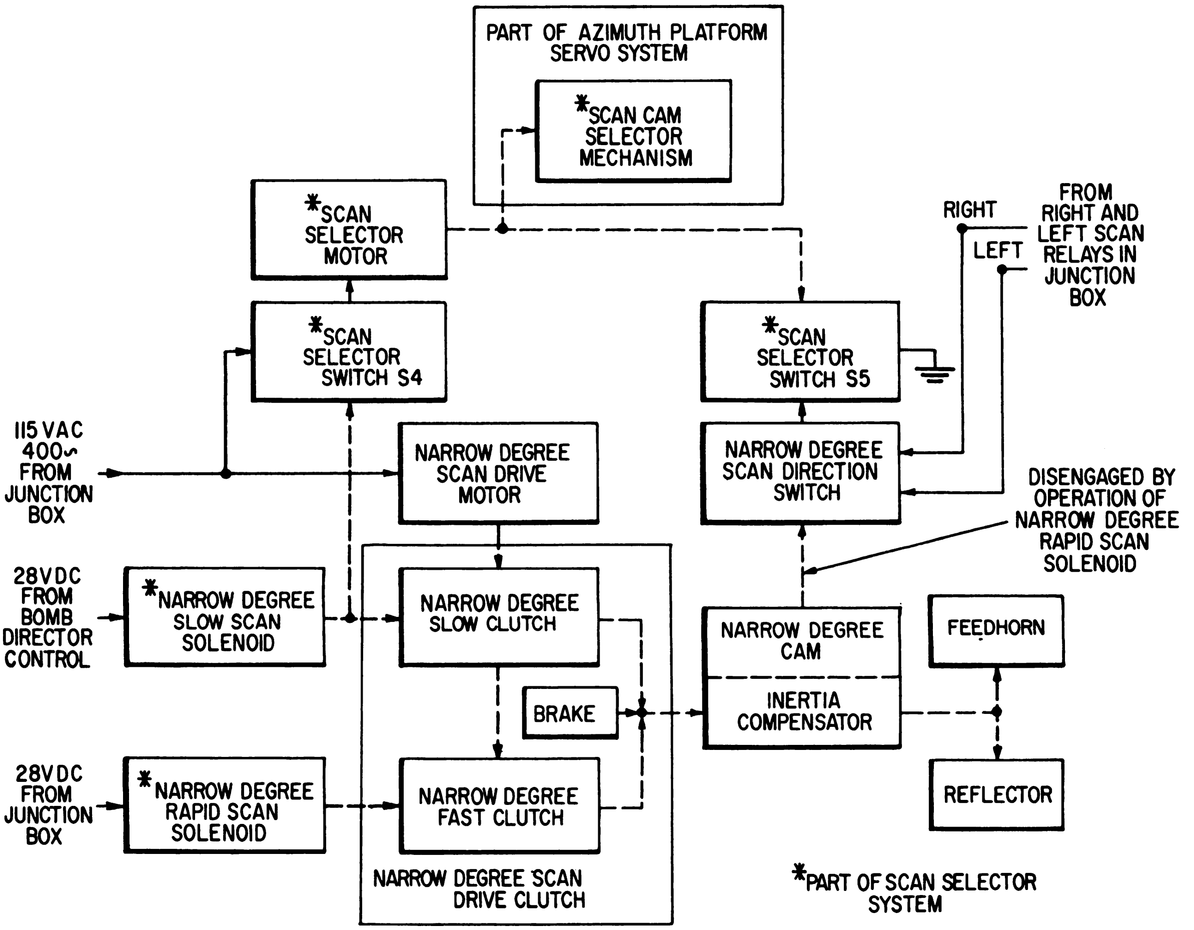
PART OF AZIMUTH PLATFORM SERVO SYSTEM
*SCAN CAM SELECTOR MECHANISM
*SCAN SELECTOR MOTOR
*SCAN SELECTOR SWITCH S4
*SCAN SELECTOR SWITCH S5
RIGHT
LEFT
FROM RIGHT AND LEFT SCAN RELAYS IN JUNCTION BOX
115 VAC 400∿ FROM JUNCTION BOX
NARROW DEGREE SCAN DRIVE MOTOR
NARROW DEGREE SCAN DIRECTION SWITCH
DISENGAGED BY OPERATION OF NARROW DEGREE RAPID SCAN SOLENOID
28VDC FROM BOMB DIRECTOR CONTROL
*NARROW DEGREE SLOW SCAN SOLENOID
NARROW DEGREE SLOW CLUTCH
NARROW DEGREE CAM
FEEDHORN
BRAKE
INERTIA COMPENSATOR
28VDC FROM JUNCTION BOX
*NARROW DEGREE RAPID SCAN SOLENOID
NARROW DEGREE FAST CLUTCH
REFLECTOR
NARROW DEGREE SCAN DRIVE CLUTCH
*PART OF SCAN SELECTOR SYSTEM

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Figure 15-21.—Antenna scan selector and narrow-scanning system.

either the optical and radar standby position, or any of the other radar positions. Thus, when the narrow slow scan solenoid is energized, the brake is released and the slow clutch transmits the rotation of the narrow scan motor in the inertia compensator. It then converts the rotation into narrow-degree oscillations. Thus, as the inertia compensator oscillates, it carries the antenna inner column, feedhorn, and the reflector, causing the antenna to scan a narrow-degree azimuth sector. This sector is centered at a position established by the θ_R input from the azimuth platform. The cam located in the inertia compensator operates the scan direction switch at the extremes of the antenna scan.

When the function switch is placed in the proper position, the rapid scan solenoids is energized. However, the slow scan solenoid is also energized at the same time. Both solenoids

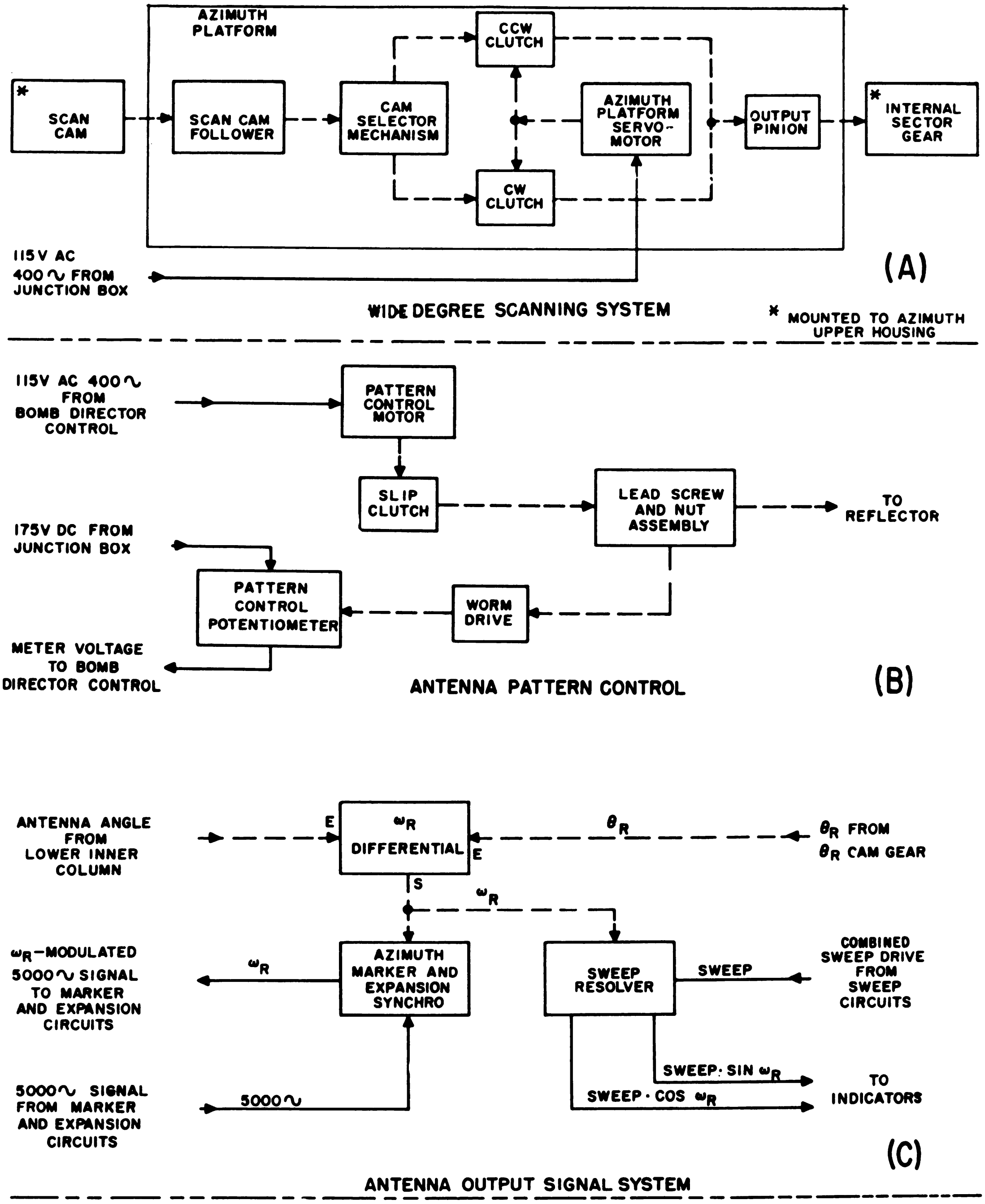

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Figure 15-22.–(A) Antenna wide-degree scanning system; (B) antenna pattern control; (C) output signal system.

act to engage the fast clutch, with the slow clutch being disengaged in the process. The inertia compensator then oscillates as previously stated.

For wide-degree scanning (fig. 15-22(A)), the azimuth platform is driven back and forth through a specified wide-degree sector centered within ±12-1/2° about the aircraft fore-and-aft axis. This motion is fed through gears in the inertia compensator to the antenna inner column, the feedhorn, and the reflector, causing the reflector to scan a wide-degree azimuth sector. The inertia compensator receives no rotational power from the narrow-degree scan drive motor; therefore, it is inoperative during wide-degree scanning operation.

The antenna pattern control (fig. 15-22 (B)) motor is operated by a switch on the bomb director control. This motor is bidirectional and drives the reflector vertically with respect to the feedhorn, and thereby changes the antenna beam pattern to give the best target returns at different altitudes.

The pattern control also furnishes the operator a meter indication of the reflector position through a worm drive and pattern control potentiometer.

ANTENNA OUTPUT SIGNAL SYSTEM

The antenna output signal system is illustrated in figure 15-22 (C). One input shaft of the mechanical differential is rotated by the scanning motion of the antenna inner column. The position of this shaft represents the antenna angle ($\omega_R - \theta_R$). The other input shaft is positioned by the azimuth servo loop which operates during both narrow and wide-degree scanning operations even though the reflector is not stabilized in azimuth during wide-degree scanning operation. Therefore, the position of this input shaft represents the relative bearing (θ_R) of the aim point. The differential adds this plus θ_R data to the ($\omega_R - \theta_R$) data, producing an output shaft rotation which is proportional to the reflected scan angle (θ_R). This output drives the shafts of the sweep resolver and the azimuth expansion synchro transmitter.

The sweep resolver receives the sweep waveform from the display channel and produces the horizontal and vertical sweeps for the PPI and the modified B-type indicator presentations.

The azimuth expansion synchro transmitter is excited by the 5,000-hertz voltage from an oscillator in the display channel. This synchro converts the mechanical θ_R data of its shaft rotation into the azimuth expansion signal for the azimuth expansion circuits and the azimuth line circuits, and into synchro data which is fed to the bombing data computer for use in producing the course marker signal.

INPUTS AND OUTPUTS OF TUNABLE RADAR SYSTEM

The block diagram (fig. 15-23) illustrates how the radar system ties into the rest of the bomb director set. The radar receives roll and pitch data from the gyro assembly, and receives all other inputs from the bombing data computer. The roll and pitch data are used to stabilize the antenna. From the bombing data computer the radar receives the various delay voltages for delaying the precision altitude trigger and the precision range line. The bombing data computer also supplies the radar system the long range sweep delay voltage and the precision range sweep delay voltage. In addition, it supplies the radar system the automatic range expansion voltage for automatically varying the length of the sweep, when using the expanded presentation at short ranges, and the relative bearing (θ_R) data for stabilizing the antenna in azimuth.

The radar system output furnishes azimuth expansion synchro data to a synchro in the bombing computer, which changes this data in accordance with relative course (η_R) data and it, in turn, supplies the resulting course marker signal to the radar.

The bombardier views the radar presentation through the eyepiece of the periscope. He then alines the selected target at the intersection of the azimuth and range-lines by operating a tracking lever which introduces range and true bearing corrections to the bombing data computer. The computer then makes the necessary corrections to the inputs of the radar system for tracking the aim point.

RADAR MAINTENANCE

The tunable radar employed with the bomb director is designed and built to give maximum operation performance under normal conditions. If the equipment is properly installed and adjusted, it should operate satisfactorily without troubles for long periods of time.

The best method to determine whether the equipment is operating properly is to subject it to a complete bench test prior to installation. If the equipment should fail to function for any cause, the information required for troubleshooting, adjusting, and repairing each component, may be found in the equipment's Service Instruction Manual. This manual presupposes that the technicians are thoroughly familiar

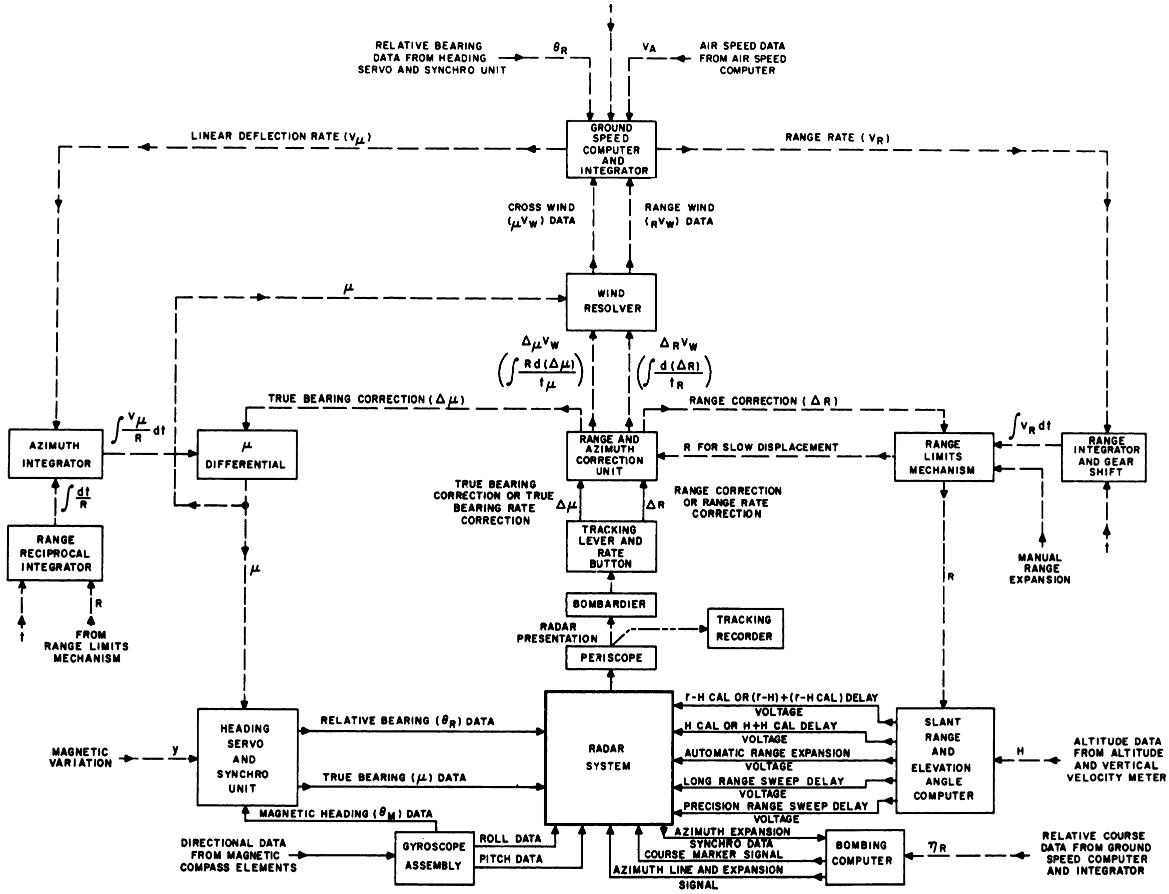
t
RELATIVE BEARING DATA FROM HEADING SERVO AND SYNCHRO UNIT
θ_R
V_A
AIR SPEED DATA FROM AIR SPEED COMPUTER
LINEAR DEFLECTION RATE (V_μ)
GROUND SPEED COMPUTER AND INTEGRATOR
RANGE RATE (V_R)
CROSS WIND ($_\mu V_W$) DATA
RANGE WIND ($_R V_W$) DATA
μ
WIND RESOLVER
$\Delta_\mu V_W$
$\left(\int \frac{R\,d(\Delta\mu)}{t_\mu}\right)$
$\Delta_R V_W$
$\left(\int \frac{d(\Delta R)}{t_R}\right)$
TRUE BEARING CORRECTION ($\Delta\mu$)
RANGE CORRECTION (ΔR)
AZIMUTH INTEGRATOR
$\int \frac{V_\mu}{R} dt$
μ DIFFERENTIAL
RANGE AND AZIMUTH CORRECTION UNIT
R FOR SLOW DISPLACEMENT
RANGE LIMITS MECHANISM
$\int V_R dt$
RANGE INTEGRATOR AND GEAR SHIFT
$\int \frac{dt}{R}$
TRUE BEARING CORRECTION OR TRUE BEARING RATE CORRECTION
$\Delta\mu$
ΔR
RANGE CORRECTION OR RANGE RATE CORRECTION
RANGE RECIPROCAL INTEGRATOR
TRACKING LEVER AND RATE BUTTON
MANUAL RANGE EXPANSION
t
μ
R
t
R
FROM RANGE LIMITS MECHANISM
BOMBARDIER
RADAR PRESENTATION
TRACKING RECORDER
PERISCOPE
HEADING SERVO AND SYNCHRO UNIT
RELATIVE BEARING (θ_R) DATA
RADAR SYSTEM
MAGNETIC VARIATION
y
TRUE BEARING (μ) DATA
MAGNETIC HEADING (θ_M) DATA
r-H CAL OR (r-H)+(r-H CAL) DELAY VOLTAGE
H CAL OR H+H CAL DELAY VOLTAGE
AUTOMATIC RANGE EXPANSION VOLTAGE
LONG RANGE SWEEP DELAY VOLTAGE
PRECISION RANGE SWEEP DELAY VOLTAGE
SLANT RANGE AND ELEVATION ANGLE COMPUTER
H
ALTITUDE DATA FROM ALTITUDE AND VERTICAL VELOCITY METER
DIRECTIONAL DATA FROM MAGNETIC COMPASS ELEMENTS
GYROSCOPE ASSEMBLY
ROLL DATA
PITCH DATA
AZIMUTH EXPANSION SYNCHRO DATA
COURSE MARKER SIGNAL
AZIMUTH LINE AND EXPANSION SIGNAL
BOMBING COMPUTER
η_R
RELATIVE COURSE DATA FROM GROUND SPEED COMPUTER AND INTEGRATOR

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Figure 15-23. –Inputs and outputs of tunable radar system.

with the physical makeup, operational characteristics, capabilities, limitations, and detailed system operation of the equipment and that he also has a knowledge of related computing equipment as discussed in chapter 17 of Aviation Fire Control Technician 3 & 2.

With the exception of the special test equipment and tools required, maintenance of the radar used within bomb director set is similar to the maintenance required on any airborne fire control radar, which is a thorough understanding of the equipment and its operation, and a logical systematic approach to its malfunctions.

COMPUTING SYSTEM

The computer used in the bomb director system described in this chapter was discussed in chapter 17 of Aviation Fire Control Technician 3 & 2. In that discussion the theory of operation of the individual subcomponents was described in detail. This chapter groups, by means of detailed block diagrams, these individual subcomponents into three primary systems. It describes the functional operation of each system and the functional relationship between the three systems. The systems are the stabilizing system, the tracking data computing system, and the release point data computing system.

STABILIZING SYSTEM

If the optical and radar sighting elements were rigidly attached to the aircraft, the optical and radar lines of sight would move with respect

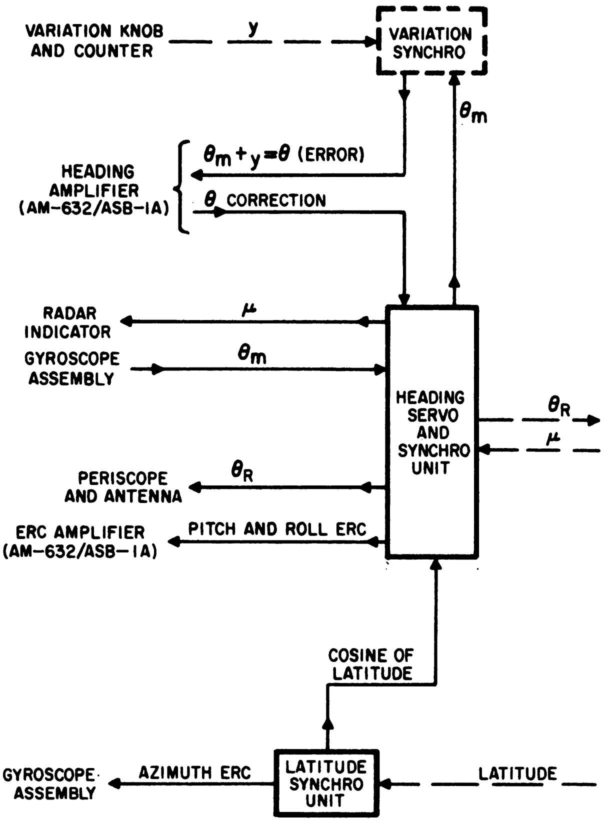

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Figure 15-24.—Part of stabilizing system.

to the aim point. This would be due to the normal roll, pitch, and change in heading rotations of the aircraft. However, the stabilizing system isolates these sighting elements from such aircraft rotations, and causes the optical and radar lines of sight to become stable.

Included in the stabilizing system are the gyroscope assembly, the magnetic compass elements, the heading servo and synchro unit, the latitude synchro unit, the stabilizing drives in the periscope and antenna, and associated amplifiers in the electronic control amplifier. Only a part of the stabilizing system is shown in figure 15-24. The heading servo and synchro unit, the variation synchro, and the latitude synchro unit are the only units of the stabilizing system that are contained in the bombing data computer.

As shown by the block diagram, this part of the stabilizing system has inputs and outputs which affect the operation of other units in the stabilizing system, as well as the other systems. The following paragraphs discuss how these units operate in the stabilizing system.

Referring to the block diagram, the mechanical inputs to these units include magnetic variations (y), true bearing (μ), and latitude. The electrical inputs are magnetic heading (θ_M) and a correction voltage from the heading amplifier in the electronic control amplifier which is identified as true heading (θ) correction in the diagram. The single mechanical output is relative bearing (θ_R). The electrical outputs include μ, θ_R, pitch and roll earth's rotation correction (ERC), and azimuth ERC. Also, the electrical output signal called θ, which originates in the variation synchro, is amplified in the heading amplifier in the electronic control amplifier for use in the heading servo and synchro unit.

The heading servo and synchro unit develops outputs of both mechanical and electrical relative bearing (θ_R) which is developed from magnetic variation (y), magnetic heading (θ_M), and true bearing (μ) as follows: θ_M and y are combined in a servo loop whose output is mechanical θ. This servo loop includes the heading differential synchro in the heading servo and synchro unit, the variation synchro on the front panel, and the heading amplifier in the electronic control amplifier. Mechanical θ is combined with mechanical (μ) in a differential to produce mechanical θ_R. Mechanical θ_R is coupled into the groundspeed computer and integrator, and the bombing computer subcomponent. In the groundspeed computer and integrator, θ_R establishes the correct angle between the airspeed vector, V_A, and the range line. This ultimately aids in the production of groundspeed (V_G). In the bombing computer subcomponent, θ_R aids in establishing the direction of the trail vector (T'), as part of the B vector solution. The end of the B vector represents the location of the impact point. (See chapter 17 of Aviation Fire Control Technician 3 & 2.) Electrical θ_R is fed to the periscope and the antenna in order that both the optical and radar lines of sight are established in the correct angle to be centered in azimuth on the aim point.

The heading servo and synchro unit also converts mechanical true bearing (μ) into its electrical equivalent, for use in the radar portion of the bomb director set to provide a north-up presentation (if used) on the screen of the radar indicator.

The latitude synchro unit (fig. 15-24) receives latitude as an input. This mechanical latitude input is converted into two electrical output signals. The first electrical output represents the cosine of latitude, and is sent to the heading servo and synchro unit, where it is developed, along with θ information, into pitch and roll ERC signals. The second electrical output from the latitude synchro unit is the azimuth ERC signal. The pitch and roll ERC signals, after being amplified by the ERC amplifier, are sent to the gyroscope assembly, where they are used to aid in maintaining the pitch and roll gyros vertical. Such compensation is required to counteract effects caused by the rotation of the earth, and also the progress of the aircraft as it changes position during flight. The azimuth ERC signal aids in maintaining the axis of the azimuth gyro stable with respect to magnetic north.

We can conclude, then, that this portion of the stabilization system causes both the radar and optical lines of sight to be rotated in azimuth to coincide with a vertical plane through the aim point. The units contained in this portion also aid in producing a north-up presentation on the screen of the radar indicator, and in stabilizing the roll, pitch, and azimuth gyros in the gyroscope assembly. The mechanical θ_R output from the heading servo and synchro unit is coupled to the groundspeed computer and integrator, where it aids in producing V_G; it is also coupled to the bombing computer subcomponent, where it aids in setting up the B vector.

TRACKING DATA COMPUTING SYSTEM

In the summary of the stabilizing system it was explained how the radar and optical lines of sight from the aircraft to the aim point were stabilized in roll, pitch, and relative bearing (θ_R). Since the aircraft is moving with respect to the aim point, it is necessary, because of this motion to track the aim point. Tracking means the positioning of the line of sight, by correctly altering the values of certain variables in the tracking data computing system, so that the crosslines continuously intersect the aim point.

To solve the tracking problem, it is necessary to establish continuously the position of the aim point relative to the aircraft. This is accomplished by tracking the aim point with respect to the three coordinates of aim point position. These three coordinates are defined as the altitude (H) of the aircraft above the aim point; the horizontal ground range (R) from the aircraft to the aim point; and the relative bearing (θ_R) of the aim point to the fore-and-aft axis (or heading) of the aircraft. H is continuously computed in the altitude and vertical velocity meter of the tracking data computing system. Horizontal tracking continuously establishes R. These values, including θ_R, are correct when the crosslines remain fixed on the aim point.

Figure 15-25 is a block diagram of the subcomponents of the tracking data computing system. Three amplifiers located in the electronic control amplifier are also used.

Inputs to the system include:

1. $\pm\Delta R$ and $\pm\Delta\mu$ or $\pm\Delta H$ as signaled by the bombardier by means of the tracking control.
2. P_S and P_V from the pitot-static tube.
3. Temp from the temperature element.
4. θ_R from the stabilizing system.
5. True course (η) from the release point data computing system.

Inputs, which are manually set in, include H_A, H_T, and initial values of longitude and latitude. Automatic range expansion is set in when the operator places the range expansion switch on the front panel to its ON position.

The principal outputs of the tracking data computing system are:

1. Control voltage and slant range ($r - H + H = r$) to the radar system.
2. Elevation angle (ϕ) to the optical system.
3. Latitude to the stabilizing system.
4. Tracking data to the release point data computing system.

The manner in which these outputs are obtained is discussed in the following paragraphs.

The inputs and outputs of the airspeed computer and the altitude and vertical velocity meter can be seen in figure 15-25. From inputs of P_V, P_S, and TEMP, the airspeed computer computes V_A, and feeds it to the groundspeed computer and integrator, which combines it

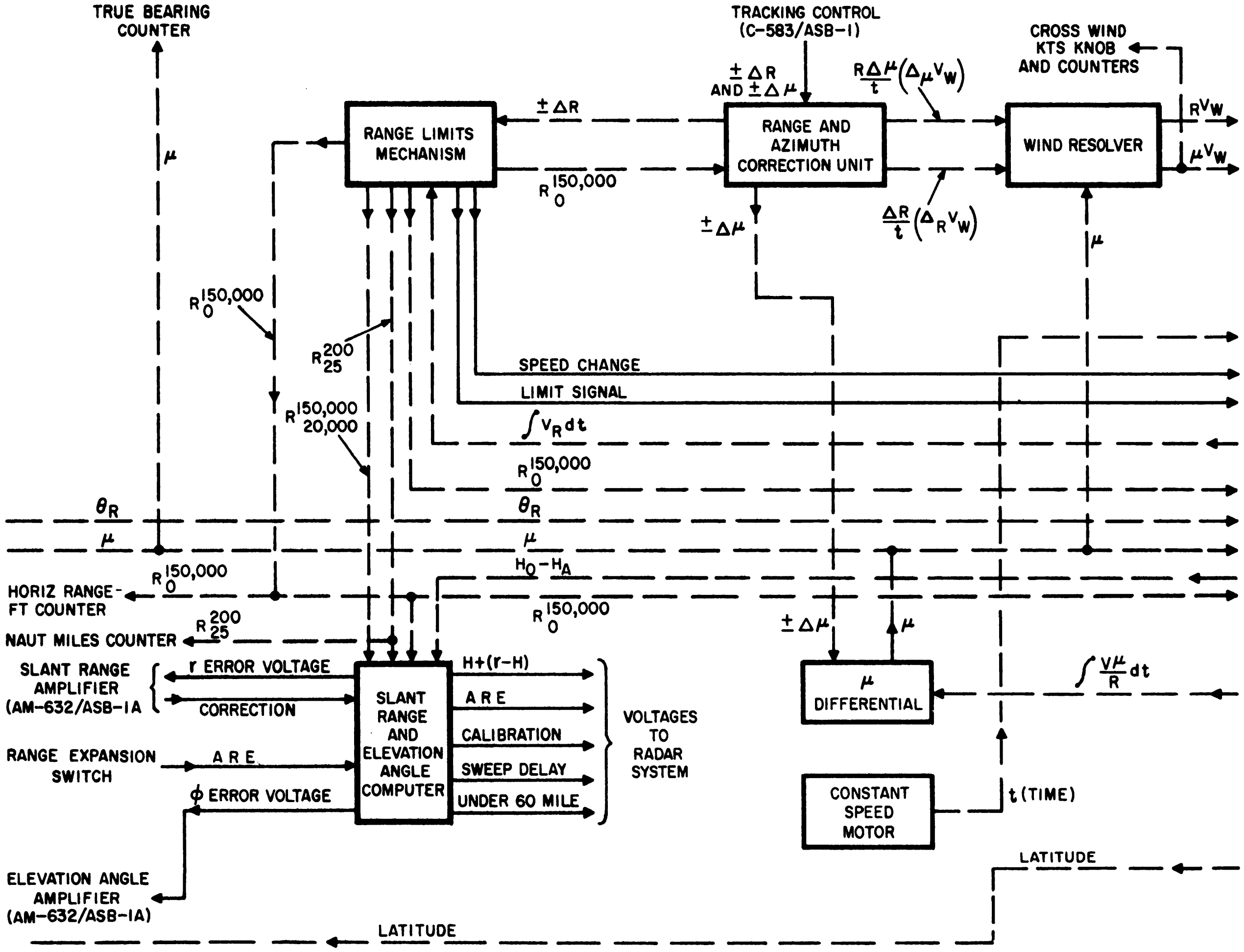

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Figure 15-25.—Tracking data computing system.

with other inputs to produce V_G. V_A is also fed to the trail computer in the release point data computing system, where, along with the computed altitude (H_C - H_A) and T inputs, it contributes to the computation of T'.

Altitude is continuously computed in the altitude and vertical velocity meter from inputs of H_A, H_T, t, P_S, and H from the tracking control. The computed altitude (H_O - H_A = H) output is fed to the slant range and elevation angle computer, where it aids in the computation of slant range to the radar system, and elevation angle to the optical system. The V_H and H_O - H_T outputs are fed to the time-of-fall computer in the release point data computing system, where, along with T, they are combined to compute t_f.

The slant range output from the slant range and elevation angle computer to the radar essentially consists of two delay voltages, r - H and H. They are combined in the radar system to produce the precision range crossline on the radar screen as seen in the eyepiece of the periscope. These two delay voltages are developed from input of $R_0^{150,000}$, from the range limits mechanism; and H, from the altitude and vertical velocity meter. The total delay of the two voltages will always represent computed slant range for ranges under 25 miles.

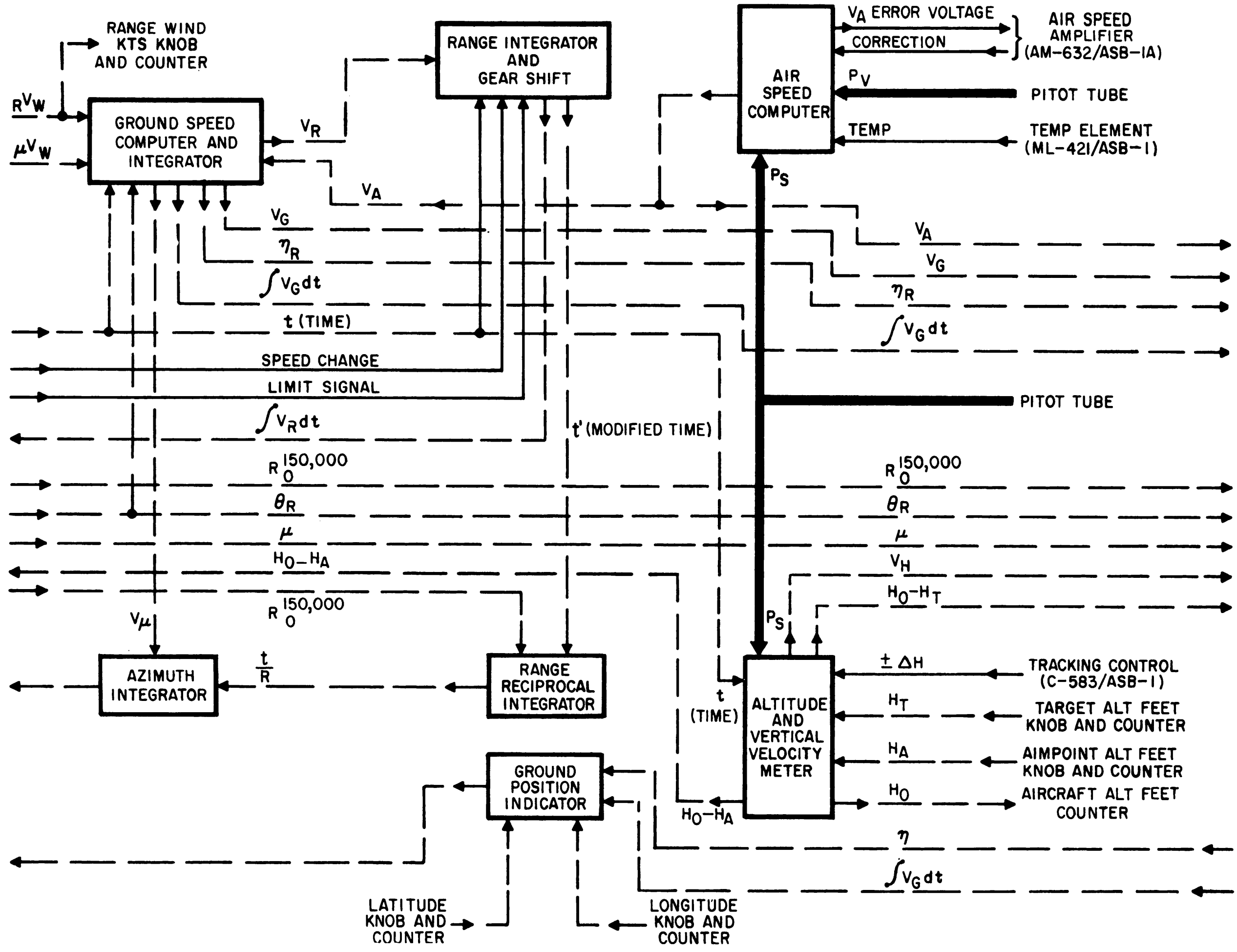
RANGE WIND KTS KNOB AND COUNTER
$_RV_W$
$_\mu V_W$
GROUND SPEED COMPUTER AND INTEGRATOR
V_R
V_A
RANGE INTEGRATOR AND GEAR SHIFT
AIR SPEED COMPUTER
V_A ERROR VOLTAGE
CORRECTION
AIR SPEED AMPLIFIER (AM-632/ASB-1A)
P_V
PITOT TUBE
TEMP
TEMP ELEMENT (ML-421/ASB-1)
P_S
V_G
η_R
$\int V_G dt$
t (TIME)
SPEED CHANGE
LIMIT SIGNAL
$\int V_R dt$
t' (MODIFIED TIME)
PITOT TUBE
$R_0^{150,000}$
θ_R
μ
H_0-H_A
V_H
H_0-H_T
V_μ
P_S
AZIMUTH INTEGRATOR
$\frac{t}{R}$
RANGE RECIPROCAL INTEGRATOR
t (TIME)
ALTITUDE AND VERTICAL VELOCITY METER
± ΔH
TRACKING CONTROL (C-583/ASB-1)
H_T
TARGET ALT FEET KNOB AND COUNTER
H_A
AIMPOINT ALT FEET KNOB AND COUNTER
H_0
AIRCRAFT ALT FEET COUNTER
GROUND POSITION INDICATOR
H_0-H_A
η
$\int V_G dt$
LATITUDE KNOB AND COUNTER
LONGITUDE KNOB AND COUNTER

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Figure 15-25.–Tracking data computing system–Continued.

The elevation angle output (φ error voltage) (fig. 15-25), consists of an error voltage which represents a change in elevation angle ($\Delta\phi$). The error voltage is fed to the elevation angle amplifier in the electronic control amplifier where it is compared with a second φ error voltage from the periscope. The resultant is amplified and sent to the φ motor (in the periscope), whose output shaft rotation is proportional to elevation angle (ϕ). The motor shaft rotation aids in positioning the elevation-level prism so that the optical line of sight represents computed elevation angle. The elevation angle error voltage is also developed from inputs of R and H in the slant range and elevation angle computer. For ranges up to 25 miles, the error voltage is developed from inputs of $R_0^{150,000}$ and H; for ranges over 25 miles, the error voltage is developed only from changes in H.

All range outputs from the range limits mechanism are computed from inputs of ±ΔR, from the range portion of the range and azimuth correction unit, and time integral of groundspeed ($\int V_R\, dt$) from the range integrator and gear shift. The $R_0^{150,000}$ is fed to the bombing computer subcomponent, of the release point data computing system, to aid in the solution of the A vector. The $R_0^{150,000}$ output also is fed to the range reciprocal integrator to aid in the production of its t/R output. The $R_0^{150,000}$ also is fed to the range and azimuth correction unit where it aids in the production of its R $\Delta\mu/t$ output. The $R_0^{150,000}$, $R_{20,000}^{150,000}$, and R_{25}^{200} outputs of the range limits mechanism are fed to the slant range and elevation angle computer to aid in producing voltages which are fed to the radar system. These voltages include H + (r - H) voltages, automatic range expansion (ARE) voltage, calibration voltages, sweep delay voltages, and an under 60 mile signal.

The $R_0^{150,000}$ input to the slant range and elevation angle computer, as mentioned previously, is also used in the production of the elevation angle, ϕ.

The $\int V_R dt$ output from the range integrator and gear shift is computed from inputs of t from the constant speed motor, and range rate (V_R) from the groundspeed computer and integrator. Electrical limit signals and speed change signals from the range limits mechanism restrict the operation of the gear shift from 0 to 200 miles, and control the t' output to the range reciprocal integrator, respectively.

The groundspeed computer and the integrator compute outputs of V_G, η_R, $\int V_G dt$, V_R, and azimuth rate (V_μ). It receives inputs of V_A from the airspeed computer; ${}_RV_W$ and ${}_\mu V_W$ from the wind resolver; ϕ_R from the stabilizing system; and t from the constant speed motor. The V_G output is fed to the groundspeed time-of-fall multiplier of the release point data computing system, which multiplies V_G and t_f to provide $V_G t_f$ output to the bombing computer subcomponent. The η_R output is also fed to the bombing computer subcomponent to aid in the solution of both the A and B vectors. The $\int F_G dt$ output is fed to the ground position indicator and to the intervalometer, of the release point data computing system. This output introduces ground velocity into the intervalometer to provide the proper bomb-spacing intervals. In the ground position indicator, $\int V_G dt$ is integrated with the η input from the release point data computing system to compute changes in latitude and longitude. The latitude output of the ground position indicator is fed to the latitude resolver and the azimuth ERC potentiometers of the latitude resolver unit. The cosine of latitude output of the latitude resolver unit ultimately produces roll and pitch ERC for the roll and pitch gyros in the gyroscope. The output of the ERC potentiometers provides azimuth ERC to the azimuth gyro.

The V_μ output from the groundspeed computer and integrator is fed to the azimuth integrator, which also receives t/R as an input from the range reciprocal integrator. The azimuth integrator multiplies these two inputs and provides an output of $\int V_\mu/R\, dt$, which represents computed changes in μ. This output is fed to one end gear of the μ differential; the other end gear receives an input of $\pm\Delta\mu$ from the true bearing correction portion of the range and azimuth correction unit when the tracking control is operated.

The output of the μ differential is fed to the bombing computer subcomponent of the release point data computing system, to the wind resolver, and to the heading servo and synchro unit of the stabilizing system. The μ input is employed in the bombing computer subcomponent as an aid in solving the A vector. In the wind resolver, the wind vector is continuously resolved in the terms of ${}_RV_W$ and ${}_\mu V_W$ with respect to changes in μ. As stated previously, the outputs of ${}_RV_W$ and ${}_\mu V_W$ are fed to the groundspeed computer and integrator. In the heading servo and synchro unit, the μ input is subtracted from ϕ to provide both mechanical and electrical ϕ_R. Mechanical ϕ_R is fed to the tracking data and release point data computing systems. As previously described in the summary of the stabilizing system, electrical ϕ_R is fed to the periscope and to the antenna for the purpose of stabilizing the optical and radar lines of sight in azimuth.

RELEASE POINT DATA COMPUTING SYSTEM

The release point data computing system is contained entirely within the bombing data computer. The system determines the proper course the aircraft must fly in order to

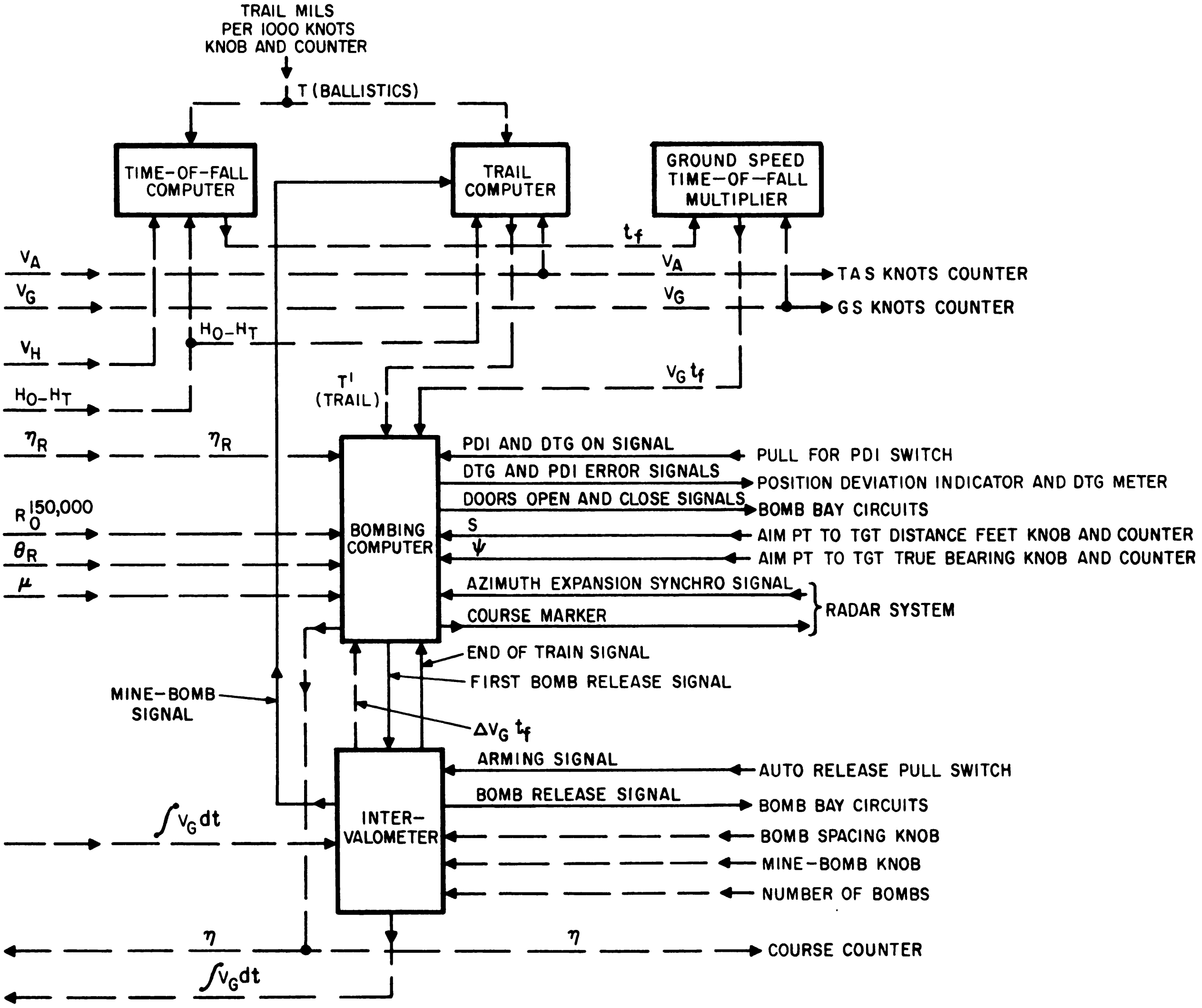

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Figure 15-26.–Release point data computing system.

have the bombs hit the target, and the distance to go before bomb release. It automatically causes the bomb bay doors to be opened, a predetermined number of bombs to be dropped, and the bomb bay doors to be closed–all at the proper time and in the proper sequence.

The release point data computing system comprises the time-of-fall computer, the groundspeed time-of-fall multiplier, the trail computer, the bombing computer, and the intervalometer. Referring to figure 15-26, it can be seen that the bombing computer is the most important subcomponent in this system, since most of the information flows into or out of the block which represents the bombing computer. In order to summarize the release point data computing system, consider the generation of the information that feeds into the bombing computer subcomponent, and then its ultimate outputs.

Inputs of $R_0^{150,000}$, η_R, and μ from the tracking data computing system and manual inputs of ψ and S to the bombing computer subcomponent, are required as inputs to the A vector solver in order for it to solve for the A vector. The end of the A vector represents the location of the target.

Inputs of η_R from the tracking data computing system, ϕ_R from the stabilizing system, T' from the trail computer, V_Gt_f from the groundspeed time-of-fall multiplier, and ΔV_Gt_f from the intervalometer are required as outputs to the B vector solver in order that it may solve for the B vector. The end of the B vector represents the location of the impact point.

The trail computer receives inputs of V_A and $H_o - H_T$ from the tracking data computing system, and T from a knob on the front panel on the bombing data computer, from which it computes T' for the bombing computer subcomponent.

The groundspeed time-of-fall multiplier receives inputs of t_f from the time-of-fall computer and V_G from the tracking data computing system, from which it computes V_Gt_f from the bombing computer subcomponent.

The intervalometer develops ΔV_Gt_f for the bombing computer subcomponent from inputs of "number of bombs" and "bomb spacing" from the knobs on the intervalometer.

Through the use of these inputs, the bombing computer subcomponent solves for both the A and B vectors, and puts out the electrical output signals for which the release point data computing system is intended.

During position deviation indicator (PDI) operation, the bombing computer subcomponent develops a PDI error signal, which aids in guiding the aircraft along the proper course to hit the target. It develops a distance-to-go signal, which is an indication of distance before bomb release. It also controls the course marker signal, which is sent to the radar portion. Finally, it sends out a signal which causes the bomb bay doors to be opened, a first bomb release signal, and a signal which closes the bomb bay doors.

The bomb release signal is sent to the bomb bay by means of the intervalometer. If more than one bomb is to be dropped, the intervalometer sends out additional release signals during the time the bomb bay doors are open. The intervalometer sends an "end of train" signal to the bombing computer subcomponent after which time the "bomb bay doors close" signal is sent out.

The mine-bomb knob on the front panel of the intervalometer causes the intervalometer to send the mine-bomb signal to the trial computer. This signal, in turn, causes the trial computer to develop trail (T') information at different rates, depending upon whether bombs or mines are being dropped. Thus, the T' input to the bombing computer is varied according to operational requirements.

Thus, it can be concluded that the release point data computing system aids in guiding the aircraft during the bomb run, and automatically controls the dropping of the bombs.

BENCH TEST AND ALINEMENT

The mechanical computer, used in the bomb director system described in this chapter and Aviation Fire Control Technician 3 & 2, consists of many subunits machined to minute tolerances and requires special equipment for testing and alining. The system exists in several configurations, making it impractical to duplicate the procedures for each in this manual. Therefore, only general procedures are presented here.

The importance of cleanliness of the working area, tools, lubricants, and solvents cannot be overemphasized. Malfunction of close-tolerance mechanical parts and electrical components can, in many instances, be attributed to dirt and foreign matter. In addition to cleanliness, it is important to maintain a dry working area. Avoid exposing any component to dampness or moisture any more than is absolutely necessary.

Each of the subunits previously mentioned are individually alined mechanically to precise positions. After alinement, the subunits are installed in the computer in a definite sequence. These units need not be alined in any particular order. However, because the installation must be performed in sequence, it is recommended that each subunit be alined in a similar sequence and installed immediately after alinement. If the settings are correct and the couplings are alined properly, the units should slide easily into place in the computer. After all subunits have been installed, remove and return all setting pins to their proper storage position.

After all subunits have been alined and properly installed and the setting pins removed, it will be necessary to perform a complete performance check to determine that the computations are correct within tolerances as set forth in the appropriate Service Instruction Manual. It can be readily seen that the most important factors in maintaining a computer of this type are cleanliness, precise alinement of each individual subunit, and adhering to the step-by-step procedures outlined for the particular system configuration.

DISPLACEMENT GYRO

The gyro assembly consists of two subassemblies–a gyro subassembly and an amplifier subassembly mounted on a common base. Three gyros and most of the mechanical and electro-mechanical elements are contained in the gyro assembly. Most of the electrical circuits are located in the amplifier.

The gyro establishes a horizontal reference plane, and with the magnetic compass elements (one in each wingtip) establishes magnetic north as a reference direction. Using these two references, the gyro assembly measures the rotation of the aircraft about any of its axes. When the aircraft pitches or rolls, the gyro assembly converts the amplitude and direction of pitch and/or roll into electrical pitch and/or roll data. When the aircraft changes direction of flight and turns in azimuth on its vertical axis, the deviation of the heading from magnetic north and the direction of such deviation is converted into electrical magnetic heading data. This data from the gyros is transmitted by synchros to the radar antenna, the periscope, and the bombing data computer.

NOTE: In some of the later equipments this information is also transmitted to the Doppler radar system groundspeed computer.

A gyroscope assembly of this type was described in Aviation Fire Control Technician 3 & 2. In this chapter a block analysis of the gyro assembly is given and squadron level maintenance such as performance checks, balance adjustments, and cleaning is discussed briefly. Many maintenance operations on the gyro assembly require the use of special test equipment found only at overhaul depots. Therefore, repairs to the gyro and replacement parts available at squadron level are limited.

GYRO ASSEMBLY BLOCK ANALYSIS

A block diagram of the gyroscope assembly is shown in figure 15-27. The solid lines connecting the blocks represent electrical signal paths; the dotted lines represent mechanical couplings; and the wavy lines represent magnetic attraction, gravitational force, acceleration, and the earth's magnetic field, as indicated. Most of the circuits center around the three gyros.

When the roll gyro becomes decentered in the pitch and roll gimbal, this gyro displaces the armature of the roll E-transformer. The roll E-transformer produces an error signal which is amplified and converted to a drive voltage by the roll centering amplifier. The drive voltage causes the roll centering servomotor to apply a torque to the roll gyro. The roll gyro then precesses until it is centered in the pitch and roll gimbal.

When the pitch gyro becomes decentered in the pitch and roll gimbal, the pitch E-transformer produces an error signal for the pitch centering amplifier. This amplifier drives the pitch centering servomotor, which applies a torque to the pitch gyro through the pitch and roll gimbal. This torque causes the pitch gyro to precess until it is centered in the pitch and roll gimbal.

When the azimuth gyro becomes decentered in the azimuth gimbal, the azimuth E-transformer, the azimuth centering amplifier, and azimuth centering servomotor operate in the same manner as their counterparts in the roll and pitch centering circuits. The azimuth centering servomotor applies a torque to the azimuth gyro through the azimuth gimbal. This torque makes the azimuth gyro precess until it is centered in the azimuth gimbal.

The motor of the roll gyro drives the roll erection roller in the roll bail. The roll bail is an inverted pendulum which senses the vertical because of the earth's gravitational attraction. If the axis of spin of the roll gyro is not vertical, the friction between the roller and the bail produces a torque which is applied to the gyro. This torque causes the gyro to precess until its axis of spin is vertical. The pitch erection roller and the pitch bail operate in exactly the same manner when the axis of spin of the pitch gyro deviates from the vertical. They apply a torque to the pitch gyro to make it precess until its axis of spin is vertical.

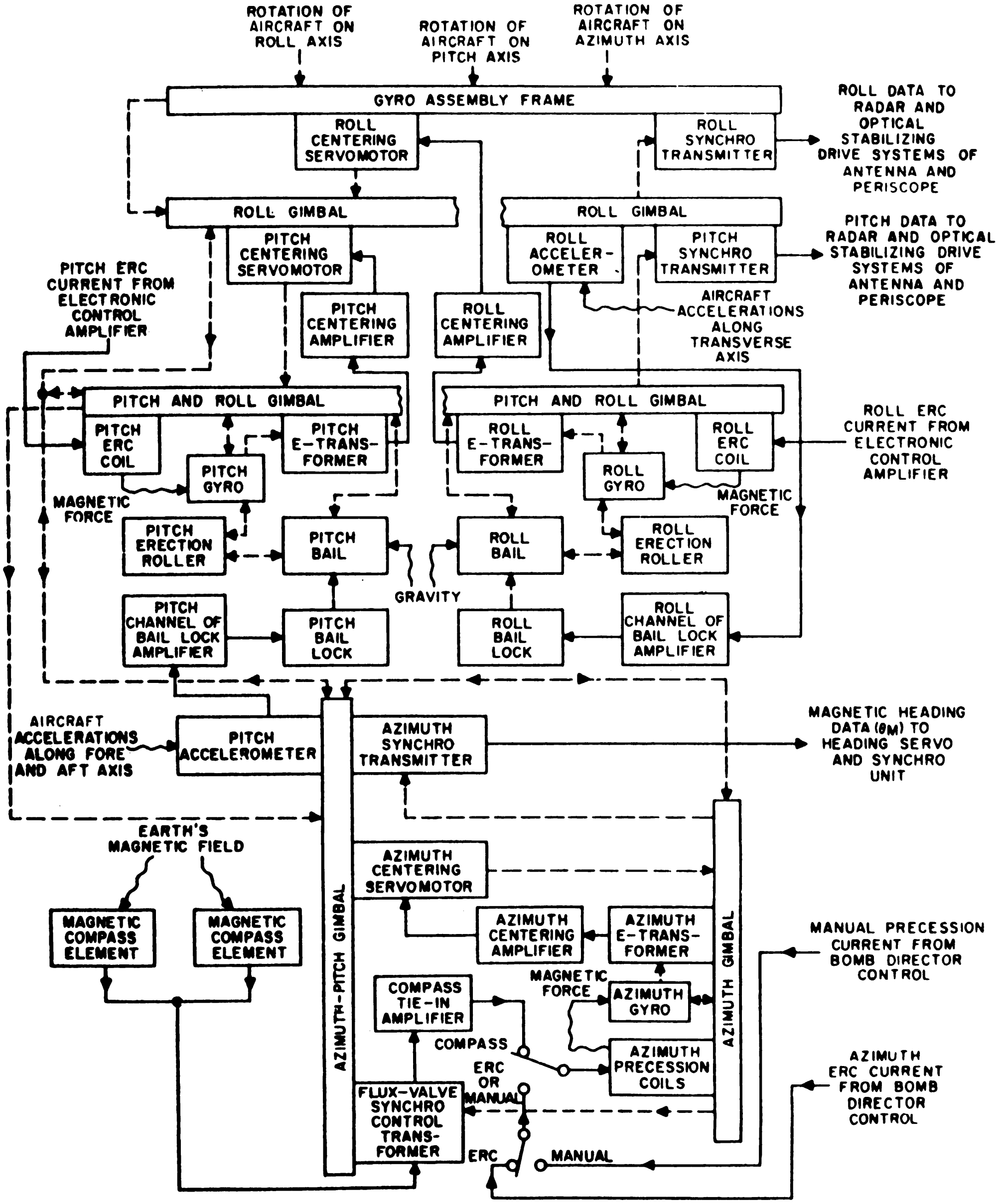
ROTATION OF AIRCRAFT ON ROLL AXIS
ROTATION OF AIRCRAFT ON PITCH AXIS
ROTATION OF AIRCRAFT ON AZIMUTH AXIS
GYRO ASSEMBLY FRAME
ROLL CENTERING SERVOMOTOR
ROLL SYNCHRO TRANSMITTER
ROLL DATA TO RADAR AND OPTICAL STABILIZING DRIVE SYSTEMS OF ANTENNA AND PERISCOPE
ROLL GIMBAL
ROLL GIMBAL
PITCH CENTERING SERVOMOTOR
ROLL ACCELER-OMETER
PITCH SYNCHRO TRANSMITTER
PITCH DATA TO RADAR AND OPTICAL STABILIZING DRIVE SYSTEMS OF ANTENNA AND PERISCOPE
PITCH ERC CURRENT FROM ELECTRONIC CONTROL AMPLIFIER
PITCH CENTERING AMPLIFIER
ROLL CENTERING AMPLIFIER
AIRCRAFT ACCELERATIONS ALONG TRANSVERSE AXIS
PITCH AND ROLL GIMBAL
PITCH AND ROLL GIMBAL
PITCH ERC COIL
PITCH E-TRANS-FORMER
PITCH GYRO
ROLL E-TRANS-FORMER
ROLL GYRO
ROLL ERC COIL
ROLL ERC CURRENT FROM ELECTRONIC CONTROL AMPLIFIER
MAGNETIC FORCE
MAGNETIC FORCE
PITCH ERECTION ROLLER
PITCH BAIL
ROLL BAIL
ROLL ERECTION ROLLER
GRAVITY
PITCH CHANNEL OF BAIL LOCK AMPLIFIER
PITCH BAIL LOCK
ROLL BAIL LOCK
ROLL CHANNEL OF BAIL LOCK AMPLIFIER
AIRCRAFT ACCELERATIONS ALONG FORE AND AFT AXIS
PITCH ACCELEROMETER
AZIMUTH SYNCHRO TRANSMITTER
MAGNETIC HEADING DATA (θM) TO HEADING SERVO AND SYNCHRO UNIT
EARTH'S MAGNETIC FIELD
AZIMUTH CENTERING SERVOMOTOR
MAGNETIC COMPASS ELEMENT
MAGNETIC COMPASS ELEMENT
AZIMUTH-PITCH GIMBAL
AZIMUTH CENTERING AMPLIFIER
AZIMUTH E-TRANS-FORMER
AZIMUTH GIMBAL
MANUAL PRECESSION CURRENT FROM BOMB DIRECTOR CONTROL
MAGNETIC FORCE
COMPASS TIE-IN AMPLIFIER
AZIMUTH GYRO
COMPASS
ERC OR MANUAL
AZIMUTH PRECESSION COILS
AZIMUTH ERC CURRENT FROM BOMB DIRECTOR CONTROL
FLUX-VALVE SYNCHRO CONTROL TRANS-FORMER
ERC
MANUAL

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Figure 15-27.—Gyroscope assembly.

As the earth rotates, and as the aircraft travels over the earth, the roll and pitch gyros would ordinarily appear to precess so that their axes of spin would not be vertical. The roll and pitch ERC coils exert continuous correcting torques in the from of magnetic attraction and repulsion. These torques cause the gyros to precess toward the vertical at exactly the same rate as the apparent precessions away from the vertical. The proper values of ERC currents are fed to the coils from the roll and pitch ERC circuits in the electronic control amplifier.

The roll and pitch bails respond to aircraft accelerations as well as to gravity.

To keep the roll and pitch gyros from precessing away from the vertical during periods of excessive accelerations, the bails are disabled at such times by means of the bail locks. The roll accelerometer on the roll gimbal produces an output signal during any acceleration which would affect the roll bail. The roll channel of the bail lock amplifier increases the amplitude of the roll accelerometer signal, and uses it to actuate a circuit for engaging the roll bail lock. The pitch accelerometer on the azimuth-pitch gimbal produces an output signal during any acceleration which affects the pitch bail. The pitch accelerometer signal is fed to the pitch channel of the bail lock amplifier, where it is used to actuate a circuit for engaging the pitch bail lock.

The two magnetic compass elements (lower left-hand corner of fig. 15-27) sense the direction of the earth's magnetic field, and supply directional data to the flux-valve synchro control transformer on the azimuth-pitch gimbal. The shaft of this control transformer is positioned by the azimuth gyro through the azimuth gimbal. Whenever the axis of spin of the azimuth gyro points to any direction except magnetic north, the control transformer produces an error signal. The compass tie-in amplifier increases the amplitude of the error signal and converts it into direct currents, which are fed through the azimuth precession coils. Because of unequal magnetic attraction between the coils and the gyro, a torque is applied to the gyro. This torque causes the gyro to precess until its axis of spin points to magnetic north.

Aircraft accelerations act upon the flux-valve compass elements in such a manner as to cause them to produce erroneous directional data. The compass tie-in amplifier is disabled (by circuits physically located in the bail lock amplifier) during excessive accelerations in order to prevent the erroneous data from making the azimuth gyro precess away from magnetic north.

When the compass tie-in amplifier is disabled, the rotation of the earth would ordinarily cause an apparent, but not actual, precession of the azimuth gyro. To correct for the apparent precession, an azimuth ERC precession current is fed through one of the azimuth precession coils during the period of the acceleration. The coil then applies a torque to the gyro to keep it precessing in a direction opposite the apparent precession and at the same rate as the apparent precession. The proper value of current to produce this rate of precession is supplied by the azimuth ERC circuit.

Provisions are also made so that a manual precession current can be fed through one precession coil or the other at any time. When the manual function is used, the operator can rapidly position the azimuth gyro as desired.

When centered and erected, the roll and pitch gyros establish the horizontal as a reference plane. With respect to this reference plane, the roll and pitch angles of the aircraft can be measured. The roll synchro transmitter on the gyro assembly frame is rotated by the roll of the aircraft, and the shaft of this synchro is positioned by the roll gimball, which is not rotated from the horizontal by the roll of the aircraft. The electrical data from this synchro represents the degree and direction of roll of the aircraft and the frame with respect to the horizontal. The pitch synchro transmitter on the roll gimbal is rotated by the pitch of the aircraft, the frame, and the roll gimbal. The shaft of this synchro is positioned by the pitch and roll gimbal, which is not rotated from the horizontal by the pitch of the aircraft. The electrical data from this synchro represents the degree and direction of pitch of the aircraft, the frame, and the roll gimbal with respect to the horizontal. The roll and pitch data from the roll and pitch synchro transmitters is fed to the radar and optical stabilizing drive systems of the antenna and the periscope.

When centered and properly precessed, the azimuth gyro establishes the magnetic north as the reference direction. With respect to this reference direction, the magnetic heading of the aircraft can be measured. The azimuth synchro transmitter on the azimuth-pitch gimbal is rotated when the aircraft changes its heading direction. The shaft of this synchro is positioned by the azimuth gimbal, which is not rotated by changes in the heading direction. The electrical data from this synchro represents the direction the aircraft is headed with respect to magnetic north. The magnetic-heading is fed to the heading servo and synchro unit of the bombing data computer.

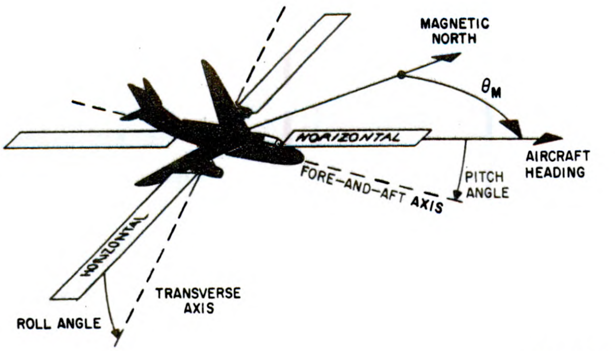

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Figure 15-28.—A combined roll, pitch, and heading flight diagram.

The flight diagram (fig. 15-28) shows the aircraft in a combined roll and pitch maneuver and illustrates the three angles measured by the gyro assembly. The roll and pitch angles are measured from the horizontal plane. The magnetic heading angle is measured clockwise from magnetic north.

CLEANING AND LUBRICATION

The gyro assembly is a very delicate mechanism and may be easily damaged if proper care is not taken to prevent excessive jarring. Therefore, when it is removed from the aircraft for any reason, it should be lifted and carried by two men using the two handles provided.

NOTE: Once a gyro has been energized, it should not be moved until it is completely stopped.

The working area in which the cleaning operations are performed should be as free from dust and moisture as possible. Smoking should be prohibited in the area, because ashes could be carried into close-fitting mechanical parts and cause their malfunctioning. No attempt should be made to clean the interior of the gyro assembly unless there is evidence of dust or dirt. When it is necessary to use a cleaning solvent, use only the type specified in the Service Instruction Manual. Use as little cleaning solvent as possible since too much solvent could possibly remove the fine lubricant film which would destroy the gyro. When a brush is used for cleaning, protect all other parts contamination by use of a clean, nonlinting cloth as a splash shield. Extreme care must be exercised at all times to prevent physical damage to all delicate parts. Unless there is evidence of damping fluid leakage, it is usually not necessary to do extensive cleaning in the gyro assembly. A thorough removal of loose dust is normally sufficient.

When cleaning the gyro, the technician must adhere to the step-by-step procedure as indicated in the Service Instruction Manual. This procedure must be performed in the order given, omitting steps when the parts involved do not require cleaning.

The gyro assembly should not be lubricated in the field, since oil applied to the parts in the gyro could possibly cause a malfunction. This would result from overoiling and getting oil on parts not requiring lubrication.

An air gun must never be used in the vicinity of an open gyro. A vacuum hose is the recommended method of removing any dust or dirt.

BALANCE ADJUSTMENTS

In making balance adjustments, an attempt is made to cause the gyros to repeat the earth's rotational rate with a specified allowable tolerance. To perform these adjustments, special test equipment and tools are required and the gyro must be removed from the aircraft.

Since the procedure is quite long and involved, no attempt is made to reproduce it in its step-by-step sequence in this course. Maintenance personnel must refer to the Service Instruction Manual for the proper procedure when attempting any maintenance on equipment requiring such close tolerances.

OPERATIONAL CHECKS

The operational performance checks of the gyro and its related circuits are actually simple and require very little time. Because of the complexity of the entire system and the need to make specified presettings of the various controls and switches, only experienced personnel who are thoroughly familiar with the system should perform these checks. Such personnel should be able to perform the checks without detailed instructions and in a relatively short period of time.

When checking for gyro operation in the system, the main points of interest are the erection of the gyros in the proper time period (indicated by the periscope image rotating toward the stabilized position), manual precession (operation observed on the course counter on the computer front panel), and magnetic compass control of the azimuth gyro (the course counter should return to its original position).

These checks are independent of the more exhaustive performance checks contained in the Service Instruction Manual, which are performed as a part of regular maintenance procedures as established by squadron maintenance control.

COMPASS ALINEMENT

The on-target mission accomplishment with the bomb directing system as described in this chapter is dependent on accurate in-flight magnetic compass directional reference. To provide directional reference, as previously mentioned, one compass element is installed in each wingtip. Actual heading signals from the two compass elements are averaged and supplied to the gyro subsystem for stabilization of the azimuth gyro. Accuracy of the direction signals from the compass elements is dependent on two factors. These factors are the magnetic north reference to the compass case being exact and compensation of the compass elements to correct for deviation induced by iron in the aircraft. Alinement and compensation of the compass elements to provide heading information correct within one-half a degree is possible by careful adherence to the alinement procedure. The maximum allowable error from actual magnetic heading is 1°.

Essentially, the method of alinement, as presented in the Service Instruction Manual, is programed as follows:

1. The establishment of magnetic bearing from the center of a compass rose to a nearby landmark.
2. Alinement of the aircraft to simulate flight attitude.
3. Determination of the centerline of the aircraft and establishment of a transit on the aircraft.
4. Indexing of the compass element case by comparison of compass element reading at various headings against known headings as determined by the transit.
5. Adjustment of the compensators to cancel deviation induced by local iron.
6. Making a final accuracy check and recording the residual error.

As can be seen, this procedure will require several pieces of special test equipment and following the prescribed procedure very carefully to prevent an unacceptable margin of error. Therefore, maintenance personnel must refer to the step-by-step instruction as set forth in the appropriate manuals.

WEAPONS ASSOCIATED WITH THE SYSTEM

The discussion thus far has been limited to the operation of a typical bomb director system. However, as an Aviation Fire Control Technician, you should have a general knowledge of what type of weapons may be used with the system.

The bomb director set, when installed in a heavy attack type aircraft, may be used for accurate release of either conventional bombs, mines, or special weapons from high altitude and while flying at high speed. The system may also be employed under all types of weather conditions.

The ballistic coefficient of the type of bomb to be dropped is effectively set into the bomb director computer when the bombardier sets the correct value of trail, in mils per thousand knots, into the computer. Therefore, the characteristics of the weapon is automatically included in the solution of the bombing problem.

Additional information on bombs and mines may be found in Naval Airborne Ordnance, NavPers 10826-B, and Aviation Ordnanceman 3 & 2, NavPers 10345-B.

CHAPTER 16

TEST EQUIPMENT

For effective operation of an aviation fire control system, it is imperative that its radar set operates at its maximum effectiveness within its designed limits. To accomplish this the technician must employ the best maintenance techniques and utilize the test equipment to the utmost.

The following discussion on the operation and circuitry of various test equipments is designed to aid in furthering knowledge of these test equipments and their use in effective maintenance of aviation fire control systems. The technician should bear in mind that this discussion is not a substitue for the test equipment's Operation Instructions or Service Instruction Manual, which should be consulted before operating any type of test equipment.

RADAR TEST SET AN/UPM-32

A general description of the Radar Test Set AN/UPM-32 and its operation is presented in Aviation Fire Control Technician 3 and 2, NavPers 10387. In this manual the functional operation and internal circuits are described in greater detail.

The AN/UPM-32 combines in one test set all the functions of a power meter, a frequency meter, a spectrum analyzer, a signal generator, and a general purpose synchroscope. Figure 16-1 illustrates the AN/UPM-32, indicating all of its front panel controls.

The general applications of the test set are as follows:

1. Measurement of power, frequency, spectrum, and frequency pulling of conventional and multipulsed radar transmitters.
2. Measurement of sensitivity and bandwidth of a radar receiver.
3. Measurement of the frequency and spectrum of a radar-receiver local oscillator.
4. Adjustment of a radar-receiver local oscillator.
5. Measurement of TR recovery time.
6. Observation of video signals.
7. Furnishing pulsed, FM or CW microwave signals.

From the preceding list of applications it should be obvious that the AN/UPM-32 is a very versatile test set and may be used in place of the FM Test Set (TS-147) and Spectrum Analyzer (TS-148) which have, in the past, had widespread usage throughout the fleet in radar testing, troubleshooting, and alinement.

OPERATING CONTROLS AND INDICATORS

Table 16-1 lists the operating controls and indicators used in operation of the AN/UPM-32. Column 1 of the table lists the control; column 2 lists the number as illustrated in figure 16-1; and column 3 lists the functions of the control indicated.

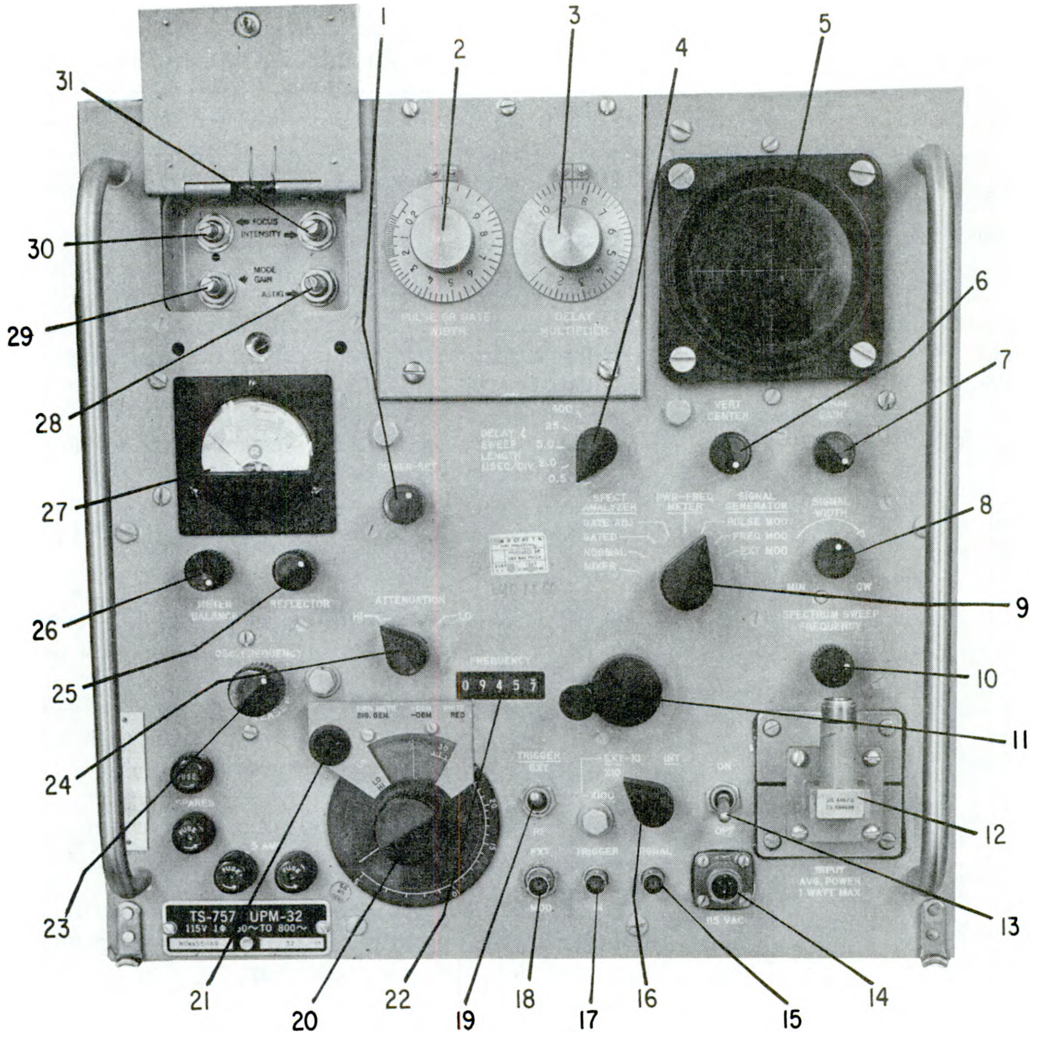
FUNCTIONAL OPERATION

The following paragraphs discuss the functions of the various assemblies in the AN/UPM-32. Details of circuit operation are given later in this chapter.

Microwave Assembly

The microwave assembly makes possible the measurement of the power level and frequency of input and output signals. The assembly consists basically of a block containing waveguides and attenuating sections. Within the assembly both the klystron signal and RF input signals are mixed to obtain a spectrum pattern. Signal flow in the assembly depends upon the setting of the function selector switch (9, fig. 16-1) to the desired mode of operation.

With the function selector switch on MIXER position, energy flow in the assembly is illustrated in figure 16-2. The power set attenuator adjusts the power level of the klystron signal. Because the klystron oscillator is sawtooth modulated by the sweep generator circuits, its output frequency varies linearly during the sawtooth excursion. Therefore, if the frequency meter is tuned to a frequency within the range covered by the klystron output, a sharp reduction in power level occurs at this particular frequency. This reduction appears as a dip in the pattern displayed on the CRT indicator. The



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1. POWER SET control.
2. PULSE OR GATE WIDTH control.
3. DELAY MULTIPLIER control.
4. DELAY and SWEEP LENGTH switch.
5. Cathode-ray tube.
6. VERT CENTER control.
7. SIGNAL GAIN control.
8. SIGNAL WIDTH control.
9. Function selector switch.
10. SPECTRUM SWEEP FREQUENCY control.
11. Frequency control.
12. RF connection.
13. ON-OFF switch.
14. 115 VAC connector.
15. SIGNAL connector.
16. SIGNAL switch.
17. TRIGGER IN connector.
18. EXT MOD connector.
19. TRIGGER switch.
20. DBM control.
21. Indicator light.
22. FREQUENCY counter.
23. OSC FREQUENCY control.
24. ATTENUATION switch.
25. REFLECTOR control.
26. METER BALANCE control.
27. Power meter.
28. ASTIG control.
29. MODE GAIN control.
30. FOCUS control.
31. INTENSITY control.

Figure 16-1. –Radar Test Set AN/UPM-32, Front panel controls.

Table 16-1—Operating controls and indicators of AN/UPM-32 (fig. 16-1).

Control	Number	Function
115 VAC connection.	14	Provides connection for line power to test set.
ON-OFF switch.	13	OFF position: Deenergizes circuits.
		ON position: Energizes circuits.
ATTENUATION switch.	24	HI position: Sets range of DBM control to HI scale.
		LO position: Sets range of DBM control to LO scale.
DBM control.	20	Adjusts attenuation of input or output microwave signals. Calibrated in dbm.
Function selector switch.	9	MIXER position: Enables observation of mode pattern of test set klystron oscillator.
		NORMAL position: Enables observation of frequency spectrum of external RF pulse.
		GATED position: Enables observation of frequency spectrum of single external RF pulse from a multipulsed radar system.
		GATE ADJ position: Enables selection of a single pulse from a pulse train for preceding GATED position.
		PWR-FREQ METER position: Enables measurement of power and frequency of external RF signals. Also enables use of test set as synchroscope.
		PULSE MOD position: Enables operation as an RF pulse-modulated signal generator.
		FREQ MOD position: Enables operation as an RF frequency-modulated signal generator.
		EXT MOD position: Enables operation as an RF signal generator whose modulation is determined by an external signal. If no external modulation is applied, the test set operates as a CW signal generator.
RF connection.	12	Provides connection for incoming or outgoing RF signals.
METER BALANCE control.	26	Zeros power meter.
Power meter.	27	Monitors standard power reference level (1 milliwatt).
FREQUENCY counter.	22	Indicates resonant frequency (in megacycles) to which frequency-meter cavity is tuned.

Table 16-1—Operating controls and indicators of AN/UPM-32 (fig. 16-1)—Continued.

Control	Number	Function
Frequency control.	11	Changes resonant frequency of meter cavity.
SIGNAL WIDTH control.	8	MIN position: Minimum pattern width on cathode-ray tube.
		CW position: Maximum pattern width on cathode-ray tube.
POWER SET control.	1	Sets output power of test set klystron oscillator. Maximum power is obtained with control set fully clockwise.
SIGNAL GAIN control.	7	Sets vertical deflection sensitivity of cathode-ray tube.
REFLECTOR control.	25	Function selector switch in MIXER position: Shifts klystron oscillator mode horizontally on cathode-ray tube.
		Function selector switch in NORMAL or GATED positions: Shifts spectrum pattern horizontally on cathode-ray tube.
		Function selector switch in FREQ MOD position: Shifts radar receiver bandpass curve horizontally on cathode-ray tube.
		Function selector switch in EXT MOD position: Adjusts klystron oscillator for maximum power output at a particular frequency.
VERT CENTER control.	6	Sets the vertical position of the trace on the cathode-ray tube.
OSC FREQUENCY control.	23	Sets output frequency of test set klystron oscillator.
TRIGGER IN connector.	17	Provides connection for incoming video triggers.
TRIGGER switch.	19	RF position: Connects detected signal, from RF connection, to sweep and pulse-generator circuits.
		EXT position: Connects external video pulse, applied to TRIGGER IN connector, to sweep and pulse generator circuits.
Cathode-ray tube.	5	Presents (visually) output signals from test set IF amplifier, video amplifier, RF mixer, and gating circuit.
SIGNAL connector.	15	Provides connection for incoming video signals.
SIGNAL switch.	16	INT position: Connects output of RF mixer to video amplifiers.

Table 16-1—Operating controls and indicators of AN/UPM-32 (fig. 16-1)—Continued.

Control	Number	Function
SIGNAL switch—Continued.	16	X1, X10, or X100 positions: Connects external video signals, applied to SIGNAL connector, to video amplifiers. The signals are attenuated by 0, 10 to 1, and 100 to 1, respectively.
DELAY and SWEEP LENGTH switch.	4	Function selector switch in GATE ADJ, PWR-FREQ METER, PULSE MOD, FREQ MOD, and EXT MOD positions: Sets sweep length on cathode-ray tube. In addition, with the function selector switch in GATED and GATE ADJ positions: Sets gate delay in conjunction with DELAY MULTIPLIER control; and with the function selector switch in PULSE MOD position: Sets pulse delay in conjunction with DELAY MULTIPLIER control.
DELAY MULTIPLIER control.	3	Function selector switch in GATED, GATE ADJ, or PULSE MOD positions: Multiplies gate or pulse delay setting on DELAY and SWEEP LENGTH switch.
SPECTRUM SWEEP FREQUENCY control.	10	Function selector switch in NORMAL or GATED positions: Sets frequency of spectrum sweep generator for best spectrum pattern on cathode-ray tube.
PULSE OR GATE WIDTH control.	2	Function selector switch in GATED or GATE ADJ positions: Varies width of gating pulse.
		Function selector switch in PULSE MOD position: Varies width of modulating pulse.
EXT MOD connector.	18	Function selector switch in EXT MOD position: Provides connection for external modulating signals.
Indicator light.	21	Lamp glows (to indicate that test circuits are energized) and illuminates DBM dial.
MODE GAIN control.	29	Adjusts amplitude of differentiated mode pattern with function switch in normal position.
ASTIG control.	28	Adjusted in conjunction with focus and intensity controls for best defined trace.
FOCUS control.	30	Adjusted in conjunction with astigmatism and intensity controls for best defined trace.
INTENSITY control.	31	Adjusted in conjunction with focus and astigmatism controls for best defined trace.

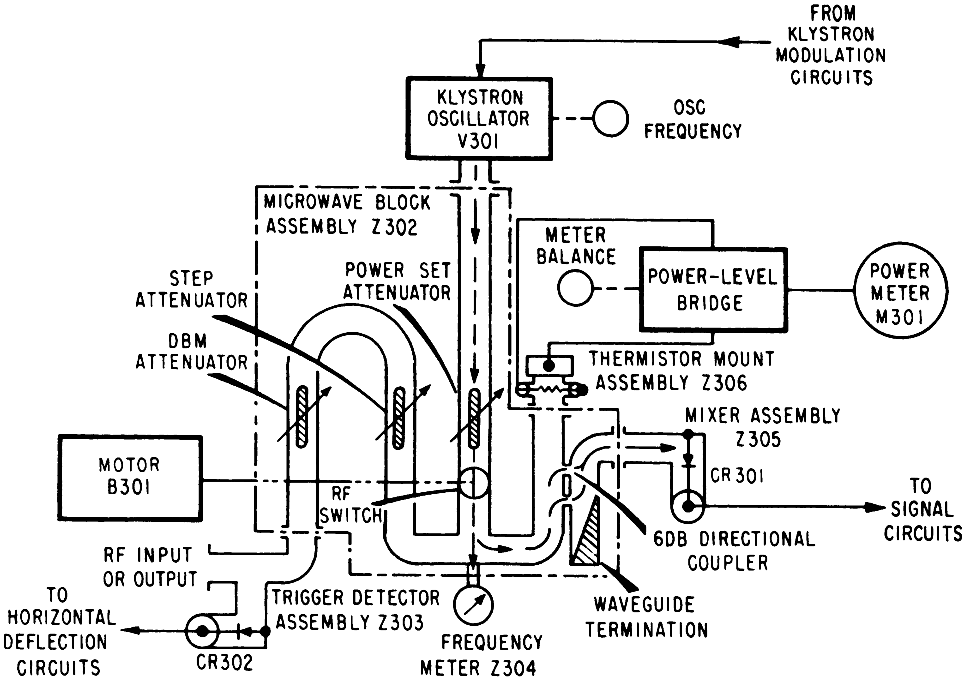

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Figure 16-2. –Energy flow in microwave assembly, function selector switch at MIXER position.

frequency of the klystron may then be read directly (in megahertz) from the frequency meter Z304.

With the function selector switch in the NORMAL or GATED position, two signals are present in the microwave assembly. (See fig. 16-3.) The klystron signal and the transmitter signal are mixed in the mixer crystal which produces heterodyne frequencies. The 45-megaHertz (MHz) component appearing during each radar output pulse passes through a tuned filter network to the IF amplifier stages. Because of the linear sawtooth modulation applied to the klystron, the klystron signal beats with a different frequency component of the radar output during each transmitted pulse interval to produce this 45-MHz beat frequency. Hence, the amplitude of each 45-MHz pulse is a measure of the power contained in the particular magnetron frequency component producing it. The magnetron spectrum is thus produced and appears on the CTR indicator. The importance of this presentation lies in the fact that with it a radar transmitter can be tuned to give a spectrum in which the greatest possible portion of the high power frequency components falls within the pass band of the radar receiver.

When the function selector switch is placed in the PWR-FREQ METER position, the radar transmitter power is fed through the microwave assembly (figure 16-4). The RF switch is closed, hence there is no power division at the T junction nor can any klystron power reach the thermistor mount. This permits measurement of the power level of the incoming signal. The step attenuator should be at its minimum (LO) position.

For the PULSE MOD, FREQ MOD and EXT MOD positions of the function selector switch, signal flow is shown in figure 16-5. The power level of the klystron RF signal is set by the power set attenuator. The frequency of the signal is indicated by the frequency meter which is used in conjunction with either the power level indicating meter or the synchroscope pattern on the CRT. Since there is an equal division of power in the T junction following the RF switch, the reading of the power level bridge meter, as modified by the DBM attenuator dial reading, gives an accurate indication of the power level of the test set output signal. The signal reaching the mixer crystal is detected, and the modulation waveform (signal) can be viewed on the CRT by setting the signal switch at INT (16, fig. 16-1) if desired.

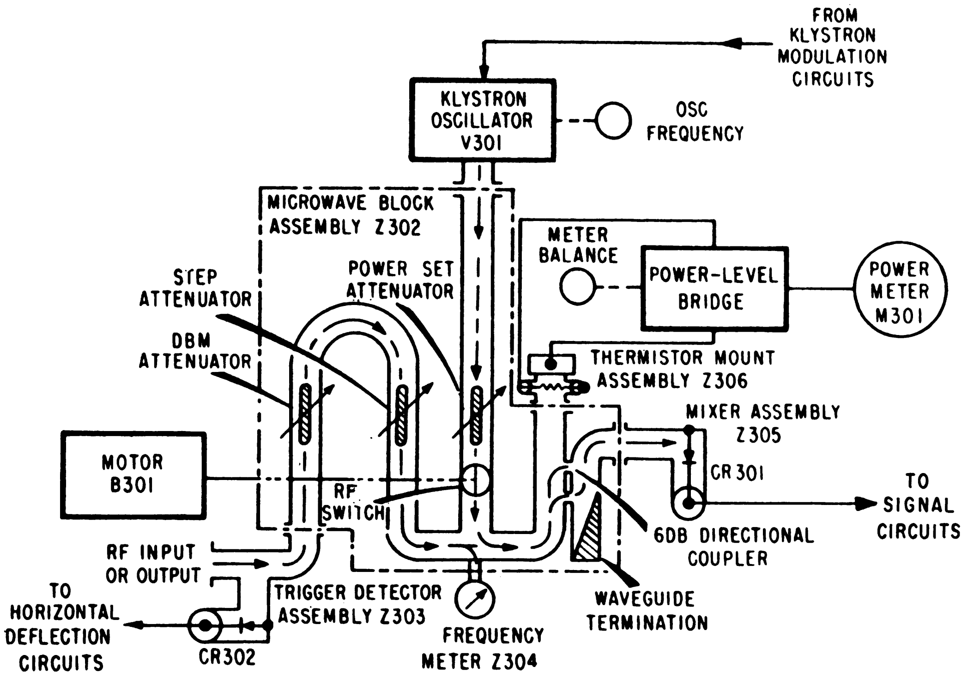

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Figure 16-3.–Energy flow in microwave assembly, function selector switch at NORMAL or GATED.

Trigger-Detector Assembly

The trigger-detector assembly (Z303, fig. 16-5) consists of a removable mount attached to the rectangular waveguide section at the input of the microwave assembly. The mount contains a crystal rectifier element (CR302) and functions as a fixed-tuned detecting section. Isolation from the main waveguide is provided by an iris which attenuates the energy from the main waveguide about 35 db to protect the crystal from burnout.

DBM Attenuator

The DBM attenuator consists of a rectangular glass vane coated with a resistive material. The vane is mounted inside the waveguide parallel to the narrow wall, and its position is continuously adjustable by the DBM control (20, fig. 16-1) from the narrow wall toward the center of the waveguide. The maximum attenuation introduced by the vane (near the center) is approximately 50 db. The calibration of the DMB dial accounts for this attenuation and the known losses in the microwave block.

Step attenuator

The step attenuator is constructed in the same fashion as the DBM attenuator. The step attenuator is controlled by the ATTENUATION switch (24, fig. 16-1) which has two settings, HI and LO. In the HI position, the vane is near the waveguide center; and in the LO position, it is adjacent to the narrow wall. For the HI position of the switch, the step attenuator introduces about 50 db of attenuation in the waveguide run.

RF Switch

The RF switch consists of a cylindrical element which closes off the waveguide leading to the klystron when the function selector switch is on the PWR-FREQ METER position. The axis of the switching device is parallel to the broad walls of the waveguide. The device has a rectangular hole through it, which lines up with the waveguide for the open position and rotates through a quarter turn to close off the waveguide run to the klystron. A metallic window which projects part way across the guide opening

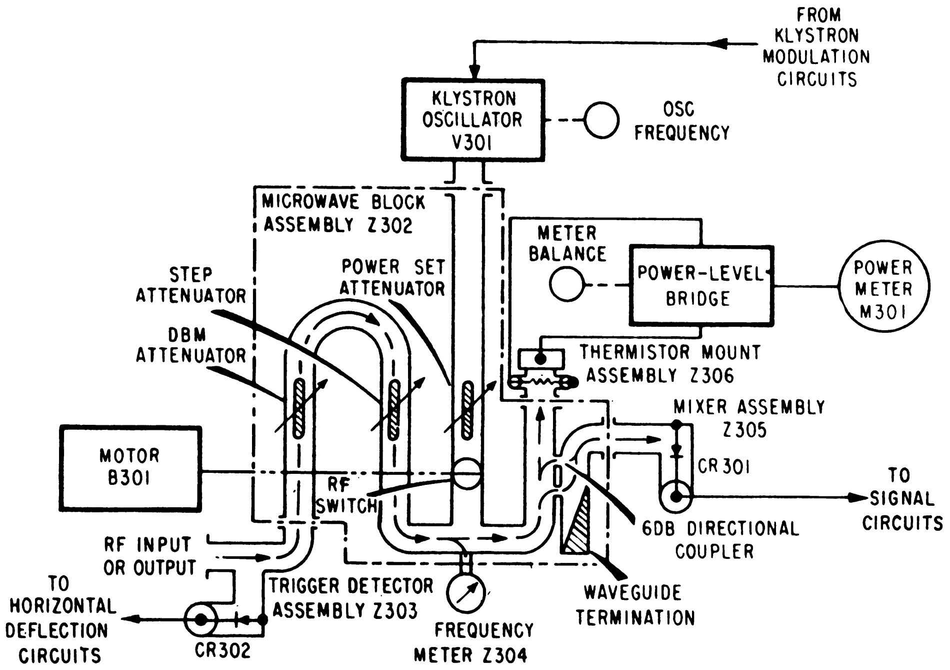

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Figure 16-4. –Energy flow in microwave assembly, function selector switch at PWR-FREQ METER position.

inside the device serves as an impedance matching device for the waveguide T.

RF Oscillator

The microwave oscillator tube (V301) used in the test set is a reflect klystron which operates on the principle of velocity modulation. The klystron may be tuned either mechanically by varying the volume of the resonator cavity or electrically by varying the reflector (repeller) plate voltage. Mechanical tuning is accomplished from the top of the klystron by the OSC FREQUENCY control (23, fig. 16-1). Electrical tuning is accomplished by the modulation sawtooth from the modulation sweep generator circuits and by the reflector control (25, fig. 16-1). NOTE: A detailed discussion of the construction and operation of the reflex klystron was given in chapter 7 of this manual.

Power Set Attenuator

The power set attenuator consists of a small rectangular glass vane coated with a resistive material. The adjustment of the vane position within the waveguide is continuous, but the assembly is not calibrated. For the maximum attenuation position near the waveguide center, the attenuator decreases the level of the klystron output signal by 20 to 25 db.

Frequency Meter

The frequency meter (Z304) consists of a circular high-Q cavity with a movable concentric tuning plunger. The frequency meter is fitted into the microwave assembly and coupled to the waveguide by means of a circular iris, and the entire assembly is hermetically sealed. The tuning plunger mechanism is geared to the frequency counter which indicates the resonant frequency of the cavity in megaHertz (MHz).

Thermistor Mount Assembly

The thermistor mount assembly (Z306) comprises a short waveguide section terminated in a housing which contains a thermistor bead. The bead is sensitive to microwave energy, and

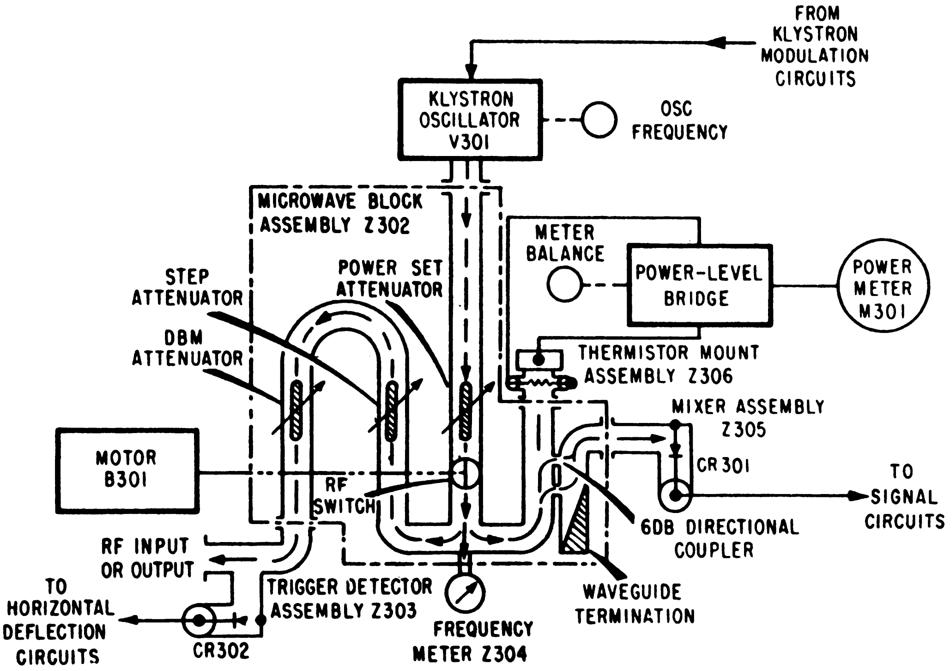

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Figure 16-5. –Energy flow in microwave assembly, function selector switch at PULSE MOD, FREQ MOD, or EXT MOD position.

its resistance changes in proportion to the level of energy in the waveguide. The assembly is mounted to the microwave section and fixed-tuned at the factory. A cylindrical subassembly is located on one side of the thermistor mount assembly to hold a disk thermistor. This thermistor has a negative temperature coefficient of resistance. The resistance changes in the disk thermistor compensate the power level bridge circuit for the effects that changes in the ambient temperature produce in the resistance of the thermistor head.

Mixer Assembly

The mixer assembly (Z305) is similar in construction to the triggerdetector assembly (Z303), and it contains the same type crystal cartridge. When the function selector is on the MIXER, PWR-FREQ METER, GATE ADJ, PULSE MOD, EXT MOD, or FREQ MOD position, the mixer crystal acts as a simple RF detector. For operation in the NORMAL and GATED positions of the function selector switch, the radar transmitter signal and the klystron signal are both present, and the output of the mixer contains beat frequencies because of the nonlinear detection characteristic of the crystal. The mixer assembly also contains a 3-db isolation pad which is adjusted when installed and must not be disturbed by the field maintenance technician.

ELECTRONIC CIRCUITS

The following discussion describes the electronic circuits of the test set. The circuits are grouped according to their particular functions. For coherence the circuit groups are described with reference to the simplified block diagram of figure 16-6. The actual circuit analysis by schematic diagrams is beyond the scope of this manual. However, with an understanding of the general circuit description which follows, the technician should have little trouble in understanding the actual detailed circuitry analysis as described in the Service Instruction Manual for the equipment.

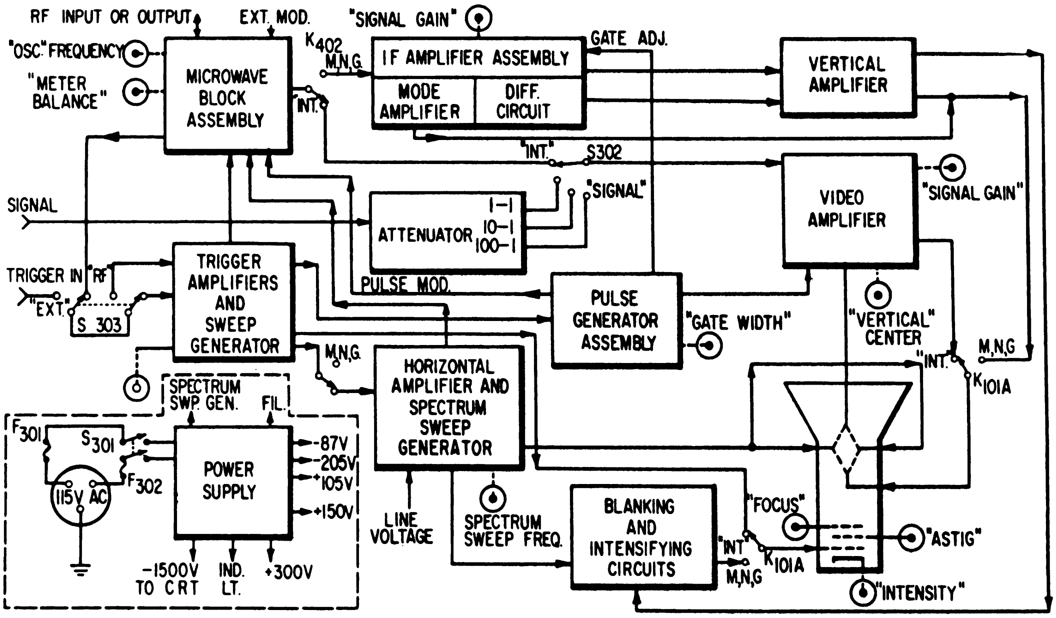

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Figure 16-6. –Radar Test Set AN/UPM-32, simplified block diagram.

Signal Circuits

The signal circuits comprise the IF amplifier assembly, mode amplifier, vertical amplifier, video amplifiers, and the associated video input attenuators. For the MIXER position of the function selector switch, the frequency modulated klystron oscillator signal is detected by the crystal in the mixer assembly (located in the microwave block assembly) and fed through relay K402 to the filter circuit located in the IF amplifier assembly. Since there is no 45-MHz component in the signal, the output of the filter circuit consists of the envelope of the detected signal which is fed to the mode amplifier. The amplified signal (mode pattern) is then fed through relay K101A to the vertical deflection plates of the CRT.

For the NORMAL and GATED positions of the function selector switch, the output of the mixer crystal is applied to the filter circuit as before. If a radar transmitter signal, is applied to the RF input, the resulting 45-MHz beat signal is amplified through the two 45-MHz IF amplifiers and mixed in the mixer (located in the IF amplifier assembly) with a 36.8 MHz local oscillator signal produced by a mode oscillator. The resultant 8.2-MHz signal is amplified, detected, and applied to the vertical amplifier. The input to the vertical amplifier now consists of two signals--a differentiated output of the mode amplifier and the detected IF signal. The abrupt changes in the mode waveform, such as the beginning and the end of the curve and the pip caused by the frequency meter (if it is tuned to a frequency within the range swept by the klyston oscillator), are retained by the differentation. Both the detected IF signal and the differentiated mode signal pass through the vertical amplifier and through relay K101A to the vertical deflection plate of the cathode-ray tube. Figure 16-7 illustrates the pattern displayed on the CRT indicator with the function selector switch in the MIXER and NORMAL or GATED positions.

In the PWR-FREQ METER position of the function selector switch or in the PULSE MOD, FREQ MOD, or EXT MOD positions, either internal or external video signals can be applied to the video amplifiers for observation on the synchroscope. (See table 16-2.) The internal signal consists of the detected radar transmitter pulse envelope which is taken from the mixer crystal and applied through relay K402, and through signal switch S302 to the video amplifier. For the observation of an external video signal, connection is made to the signal connector and the signal switch thrown to EXT.

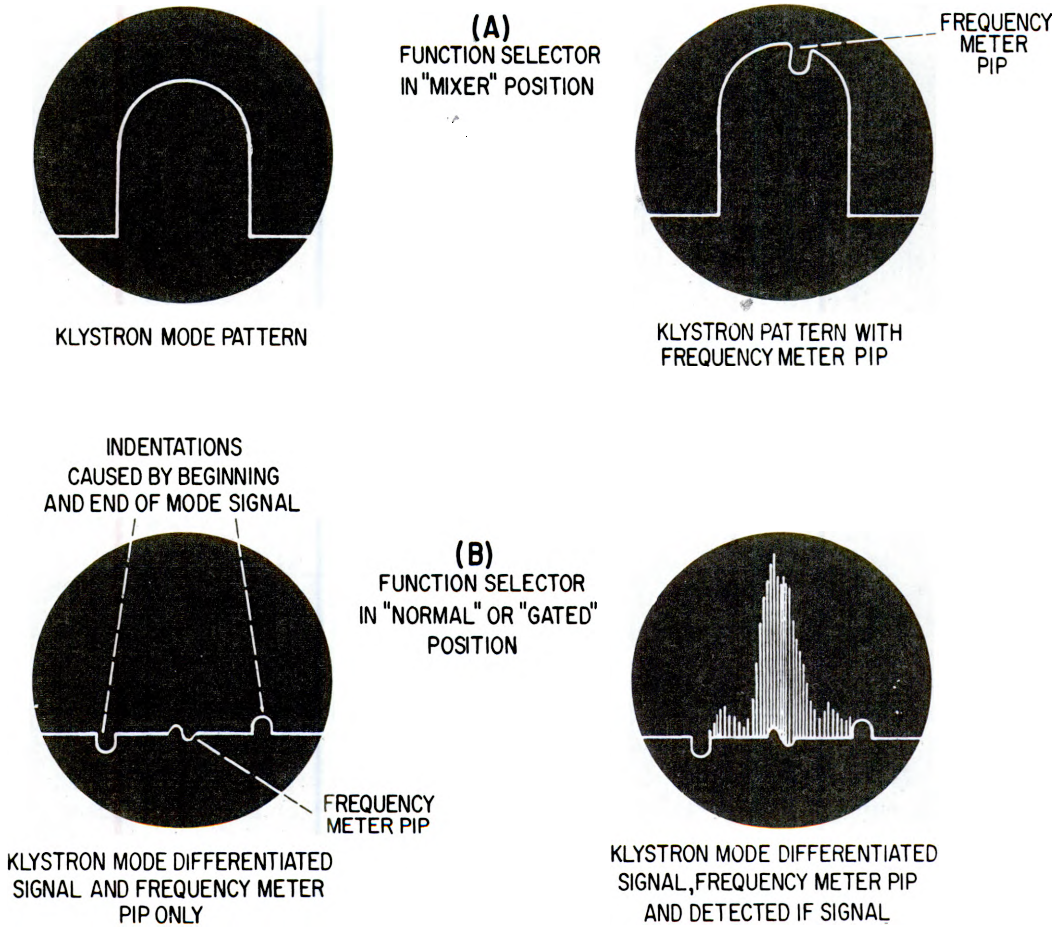
(A)
FUNCTION SELECTOR
IN "MIXER" POSITION
FREQUENCY METER PIP
KLYSTRON MODE PATTERN
KLYSTRON PATTERN WITH FREQUENCY METER PIP
INDENTATIONS CAUSED BY BEGINNING AND END OF MODE SIGNAL
(B)
FUNCTION SELECTOR
IN "NORMAL" OR "GATED" POSITION
FREQUENCY METER PIP
KLYSTRON MODE DIFFERENTIATED SIGNAL AND FREQUENCY METER PIP ONLY
KLYSTRON MODE DIFFERENTIATED SIGNAL, FREQUENCY METER PIP AND DETECTED IF SIGNAL

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Figure 16-7. –Display patterns of the CRT. (A) MIXER position; (B) NORMAL or GATED position.

Depending on the setting of signal switch S302, the video signal is either fed directly or attenuated as desired before being applied to the video amplifier. The video amplifier stages drive the vertical deflection circuit of the CRT for the synchroscope video display.

Trigger Amplification and Horizontal Deflection Circuits

The trigger amplifier stage is used to amplify the input triggers which are used to synchronize the synchroscope sweep generator for the cathode-ray tube trace. The sweep generator may be triggered either externally or internally, depending on the position of the trigger switch S303. On EXT, the trigger may be taken from an outside source and applied to the trigger amplifier for starting the sweep generator. On RF, the trigger originates at the trigger detector assembly, located in the microwave block assembly, and is fed through the trigger switch to the trigger amplifier for starting the sweep.

For the MIXER, NORMAL, and GATED positions of the function selector switch, the source of the horizontal deflection voltage is the free-running spectrum sweep generator. The sweep generator is synchronized at line frequency or subharmonics of it by an a-c voltage from the power supply. The output of the spectrum sweep generator (a sawtooth voltage) is fed to the horizontal amplifier. The horizontal amplifier drives the horizontal plates of the

Table 16-2.—AN/UPM-32 presentations.

Function	Signal switch position	Scope vertical presentation
MIXER	INT	Klystron RF envelope.
MIXER	EXT	Do.
NORMAL	INT	Spectra plus differentiated RF envelope.
NORMAL	EXT	Do.
GATED	INT	Gated spectra plus differentiated klystron RF envelope.
GATED	EXT	Do.
GATE ADJ	INT	Envelope of RF input plus internal video gate.
GATE ADJ	EXT	Internal video gate plus external video.
PWR-FREQ METER	INT	Envelope of RF input.
PWR-FREQ METER	EXT	External video.
PULSE MOD	INT	Envelope of RF input plus RF output.
PULSE MOD	EXT	External video.
FREQ MOD	INT	Envelope of RF input plus RF output.
FREQ MOD	EXT	External video.
EXT MOD	INT	Envelope of RF input plus RF output.
EXT MOD	EXT	External video.

NOTE: The frequency meter can cause a dip or reduction of power on any of the above internal or external RF derived waveforms if tuned to the proper frequency.

cathode-ray tube through a push-pull arrangement.

For the GATE ADJUST position of the function selector switch, the horizontal deflection voltage originates in the synchroscope sweep generator. Through the synchroscope sweep generator can be triggered by the detected transmitter pulses from the trigger detector, the generator is normally triggered by an externally applied trigger to permit observation of all the detected radar transmitter pulses on the CRT indicator. The sweep voltage is taken from the generator to the horizontal amplifier and then applied to the horizontal deflection plates.

For the PWR-FREQ METER, PULSE MOD, FREQ MOD, and EXT MOD positions of the function selector switch, the synchroscope sweep generator is again used as a source of horizontal deflection voltage. However, the sweep generator is triggered by either the first detected RF pulse from the trigger detector or by an external trigger as desired.

Blanking and Intensifying Circuit

For the MIXER , NORMAL, and GATED positions of the function selector switch, the output from the spectrum sweep generator is differentiated and fed to the blanking and intensifying circuits as a blanking signal. The output of the vertical amplifier is also fed to the blanking and intensifying circuits as an intensifying signal. The signal output is fed through relay K101A to the control grid of the cathode-ray tube and is used to blank the screen during flyback time and to intensify during sweep time. For synchroscope operation, however, an unblanking signal is taken from the synchroscope sweep generator circuits and fed through relay K101A to the CRT control grid for intensifying the sweep.

Pulse Generator Assembly Circuits

The pulse generator circuits consists of the trigger delay circuits and the pulse modulator circuits. The function of the delay circuit is to control and adjust the starting point of the gating waveform applied to the IF amplifier. With the function selector switch in the GATE ADJ position, it permits centering of the gating pulse over the desired radar transmitter pulse. When the function selector switch is then switched to the GATED position, only the spectrum of the chosen radar transmitter pulse is displayed.

For the PULSE MOD position of the function selector switch, a negative pulse is taken from the pulse modulator circuits and applied to the klystron reflector. Then, once for each applied trigger, the klystron is driven into oscillation for the duration of the pulse.

Klystron Modulation Circuits

The test set klystron oscillator, located physically in the microwave block assembly, operates as a CW signal depending on the position of the function selection switch and the type of operation desired. For the MIXER, NORMAL, and GATED positions, the klystron is frequency modulated by a sawtooth voltage from the spectrum sweep generator. For the PULSE MOD position of the function selector switch, the klystron is pulse modulated by the pulse generator assembly as previously discussed. For the FREQ MOD position, the klystron is switched by relay action to the output of the synchroscope sweep generator. The signal consists of an exponential charging waveform, and its repetition rate depends upon that of the trigger applied to the synchroscope sweep generator. For the EXT MOD position, the EXT MOD connector is switched by relay action directly to the klystron for an external modulation signal input.

Power Supply Circuit

The power supply consists of four separate circuits for d-c supply voltages in addition to the a-c filament supply. They are all fed from a common power transformer located in the power supply assembly.

The high voltage supply delivers a negative 1,500 volts, unregulated, to the CRT for an accelerating voltage.

The plate and screen supply voltages are taken from a regulated circuit which has four output voltage levels. The primary output, +300 volts, is supplied to the pulse generator, the klystron oscillator, and to the various circuits. A +500-volt output is used for feeding the pulse generator and power level bridge circuits. Another +150-volt output is fed to the IF amplifier section. A fourth output of +105 volts supplies the screen grid circuits of the IF amplifiers.

Biasing voltages are taken from a separate regulated supply. The negative 205-volt output is the main bias voltage used throughout the test set. A separate negative 87-volt output is used for the vertical amplifier and spectrum sweep generator biasing voltages.

The fourth d-c supply circuit consists of a full wave rectifier bridge circuit which produces a +28-volt d-c supply. This circuit supplies 28 volts d.c. for energizing the relays in the test set and energizing the motor which opens and closes the RF switch in the waveguide.

THEORY AND ANALYSIS OF A SPECTRUM

Prior to a discussion on the alinement and maintenance of the AN/UPM-32 and for a better understanding of the test set in general, a brief discussion on the basic principles, application, and practical value of a spectrum analysis is given in the following paragraphs.

Basic Principles

In conventional circuit theory, any repetitive waveform can be analyzed by the use of

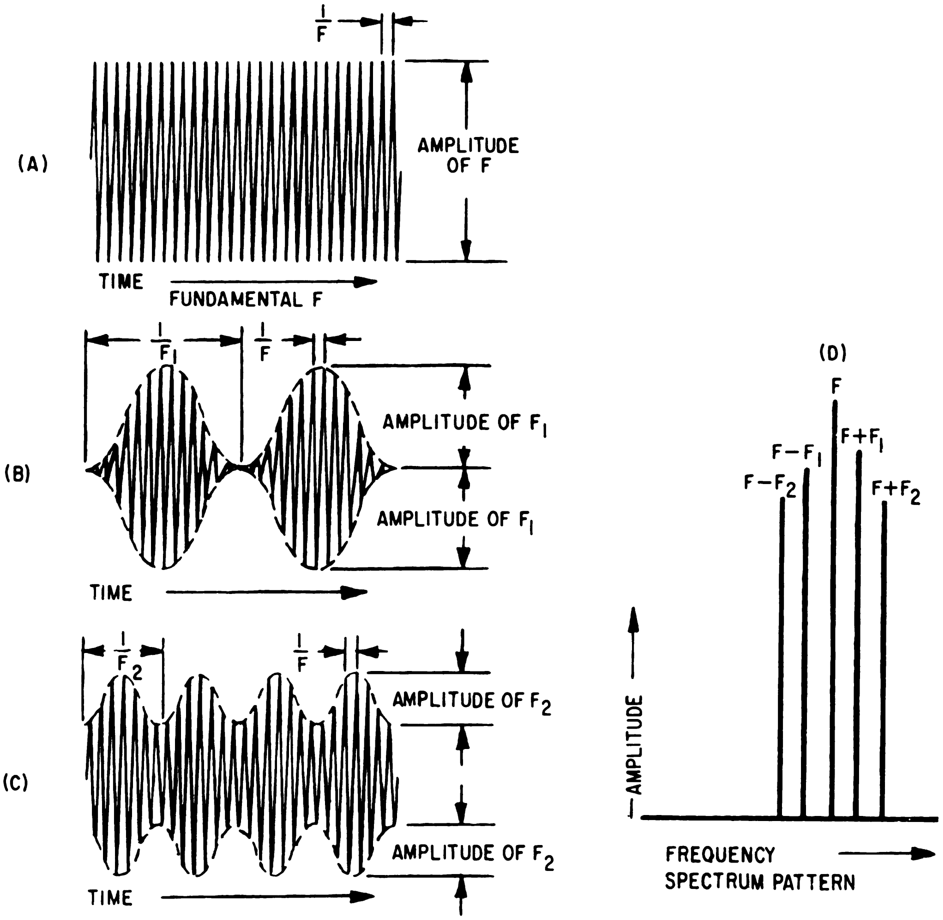

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Figure 16-8.—Formation of a spectrum.

Fourier equations. This type of analysis shows that a square wave, or any other nonsinusoidal repetitive wave, consists of a fundamental sine wave plus an infinite number of harmonics. The pulsed output of a radar transmitter can be treated in the same manner.

The process of modulation inherently produces frequencies other than the modulated or modulating frequencies themselves. When the frequencies resulting from a modulation process are plotted on a horizontal scale and the energy distribution among these frequencies is plotted on a vertical scale, the result is a frequency power plot, more commonly known as a spectrum. Figure 16-8 (D) illustrates the spectrum resulting when a fundamental frequency F is modulated by arbitrarily chosen frequencies F_1 and F_2. Actually there are an infinite number of frequencies present even in the simple modulation of one sine wave by another, but the amplitudes of the higher order harmonics are negligible.

If the fundamental frequency F (fig. 16-8(A)) is modulated by F_1, the resultant waveform will appear as illustrated in figure 16-8(B). In the spectrum pattern (fig. 16-8 (D)), the modulation by F_1 causes two other frequencies to appear, $F + F_1$ and $F - F_1$, respectively.

Figure 16-8 (C) shows the effect of modulating the fundamental frequency F with a frequency F_2 which is twice the frequency of F_1. The result is the appearance of two new frequencies in the spectrum which are indicated as $F + F_2$ and $F - F_2$.

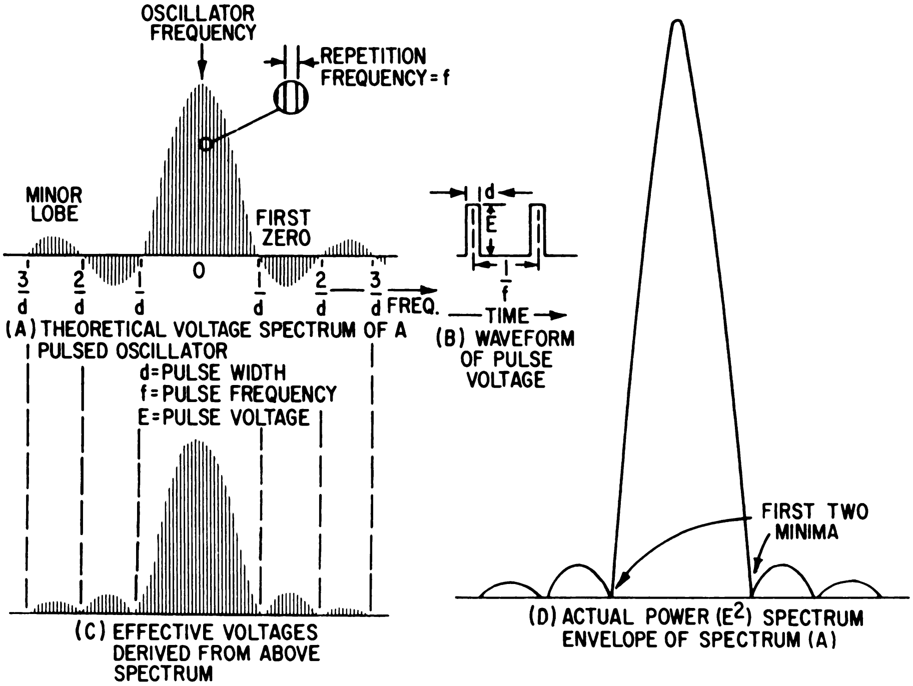
OSCILLATOR FREQUENCY
REPETITION FREQUENCY = f
MINOR LOBE
FIRST ZERO
3/d
2/d
1/d
0
1/d
2/d
3/d
FREQ.
(A) THEORETICAL VOLTAGE SPECTRUM OF A PULSED OSCILLATOR
d=PULSE WIDTH
f=PULSE FREQUENCY
E=PULSE VOLTAGE
d
E
1/f
TIME
(B) WAVEFORM OF PULSE VOLTAGE
(C) EFFECTIVE VOLTAGES DERIVED FROM ABOVE SPECTRUM
FIRST TWO MINIMA
(D) ACTUAL POWER (E2) SPECTRUM ENVELOPE OF SPECTRUM (A)

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Figure 16-9.—Conversion of a voltage spectrum to a power spectrum.

Application of Principles to a Pulsed Oscillator

Although the duration of a pulse is extremely small compared to the repetition rate in a typical radar system, the output can be visualized for purposes of analysis as a continuous wave of RF energy which is periodically interrupted. This in effect is the same as taking the continuous RF wave and modulating it with a repetitive rectangular pulse. Since the pulse itself contains an infinite number of harmonics of its own repetition frequency, each of these harmonic frequencies and the repetition frequency modulate the continuous wave. Hence, a spectrum evolves in the manner explained in the preceding discussion except that there are an infinite number of sideband components.

Figure 16-9 (A) illustrates a theoretical voltage spectrum of a pulsed oscillator. Though not shown, an infinite number of negligibly small sideband components extend from either side of the limits of the diagram. Any two adjacent sideband components are separated by a distance on the frequency scale which is equal to the repetition rate of the rectangular pulses (fig. 16-9 (B)), because each component bears a harmonic relationship to the repetition frequency.

Neither of the voltage spectra shown in figure 16-9 (A) and (C) is actually seen on the test set scope because of a square-law detector incorporated in the test instrument. This detector converts the voltage into the power spectrum illustrated in figure 16-9 (D).

Practical Value of Analysis

With a knowledge of how a spectrum is formed and what it indicates, a visual examination of a radar spectrum is valuable in the following three general ways:

1. In checking for stability of a magnetron.
2. In tuning a radar system so that most of the output power is within the frequency range of the receiver bandpass response.
3. In analyzing radar system outputs to determine causes of poor spectra.

It is important to note that the shape of the spectrum of a pulsed signal depends chiefly upon the following two characteristics of the signal:

1. The modulation envelope of the pulse.
2. The shifting of the oscillator frequency during the pulse.

In general, the following statements apply in the analysis of a spectrum:

1. The ideal spectrum is achieved when the pulse is truly rectangular and there is no frequency modulation.
2. The distance between the first two minima of an ideal spectrum is a measure of the pulse width of the signal.
3. The distance between the first two minima should not be much greater than the receiver bandwidth, because by far the greatest amount of power is in the center lobe of an ideal spectrum.
4. An effect of frequency modulation is to increase the amplitude of the side lobes.
5. A large number of side lobes indicates the presence of amplitude modulation.
6. A spectrum without deep minimum points adjacent to the main lobe indicates the presence of frequency modulation.
7. If the spectrum has two peaks, the magnetron is operating in two modes or else is being pulled in frequency by some external force, such as a poorly matched rotating scanner or fluctuating voltages.
8. The frequency difference between two peaks indicates the amount of frequency pulling. The height indicates the relative power at the frequency of each peak.

OPERATING THE TEST SET

Complete operating instructions for the AN/UPM-32 are given in the Service Instruction Manual, and several checkout procedures have been written for various radar sets which describe the use of the test set on particular radars. Accordingly, a complete procedure will not be included here; instead, a few tricks-of-the-trade will be given to help the technician avoid crystal damage and obtain the best view of the transmitter spectrum.

Any technician can learn to operate this test set without following a written procedure every time if he will spend a few hours familiarizing himself with the test set and its operation. In fact, this should be a goal for every technician.

Preventing Crystal Damage

To prevent damaging the mixer crystal, always adjust the POWER SET knob with the function switch in the EXT MOD position using the following procedure:

1. Balance the meter with the function switch in the PWR-FREQ METER position.
2. Turn the function switch to the EXT MOD position and adjust the REFLECTOR control for a peak reading on the meter.
3. Adjust the POWER SET control for a SET POWER reading on the meter.

CAUTION: Never move the POWER SET control from this position except for slight touchup adjustments when calibrating the test set.

It is important to remember that the REFLECTOR control must be adjusted for a peak meter reading before turning the POWER SET knob too far (more than 5 or 6 turns clockwise) to obtain the SET POWER reading on the meter. It is possible to set the REFLECTOR control so that the klystron will not oscillate. Of course, the POWER SET control can then be turned fully clockwise without obtaining a reading on the meter; however, if the REFLECTOR control is then turned slightly, it will cause the meter to peg and probably burn out the mixer crystal.

Viewing a Radar Transmitter Spectrum

When making the final control setting on this test set for viewing a radar transmitter spectrum, the technician should keep in mind that the best possible picture of the spectrum will always be obtained when the SPECTRUM SWEEP FREQUENCY control is fully counterclockwise (or very nearly so) and the SIGNAL WIDTH control is nearly maximum (approximately 1/8 turn from full clockwise).

MAINTENANCE

The information presented in this section is intended to aid the Aviation Fire Control Technician in the prevention and correction of troubles in Radar Test Set AN/UPM-32.

A thorough knowledge of the material covered thus far, as to physical makeup, characteristics, capabilities, limitations, and general theory of operation, will greatly facilitate maintenance procedures.

The technician should bear in mind that the operation of this equipment involves high voltages which are dangerous to life. Maintenance personnel must observe safety regulations at all times.

No maintenance should be attempted on the equipment without the test set's Service Instruction Manual for ready reference. Section V of this manual lists in table form the minimum performance standards of the test set. It includes the purpose of the check, procedure, normal indications, and a list of possible causes of abnormal indications. Section V of the Service Instruction Manual also lists a step-by-step procedure for isolation of a trouble to a faulty circuit, group of circuits, or part. A system of symbols is used in the check charts for indicating in the equipment where test connections are made for measuring or observing electrical data. The symbols are divided into three classes—major, secondary, and minor test points. The major test points are assigned to critical points in circuits, interconnecting assemblies, and input/output connections. These points are used to localize a trouble to a particular assembly or group. Secondary test points are generally assigned to critical points between circuits within an assembly. These points are used in localizing trouble to a particular circuit of the assembly. Minor test points are assigned to points within circuits bracketed by secondary test points. These are used to isolate the trouble to a particular stage of the circuit.

Section V of the Service Instruction Manual also lists in detail the removal and replacement instructions for assemblies, subassemblies, and parts which might be found faulty in the performance and trouble analysis checks. It lists the step-by-step procedure for minor repairs and adjustments necessary after the replacement of parts for the test set to meet the minimum performance standards.

ALINEMENT

The complete procedures for alinement and adjustment of the test set are contained in section VI of the Service Instruction Manual. The control or adjustments described in the manual need only be checked occasionally or whenever a tube or detail part is replaced in the circuitry directly associated with any given control.

Section VI lists the detailed procedures for alining the following units:

1. IF amplifier assembly.
2. Video amplifiers.
3. Pulse generator assembly.

It also lists in table form a complete schedule for maintenance inspections, listing the item to be checked, inspection required, and the time interval between inspections. (NOTE: The test set should be turned in to the activity's overhaul center after each 2,000 hours of operating time.)

Another important maintenance aid included in section VI is the description of bench test setups utilizing the test set. It includes cabling details for interconnecting the test set and the test equipment used in the minimum performance procedures discussed previously.

Section VII of the Service Instruction Manual consists of information and diagrams used in both maintenance and alinement. The diagrams will be especially useful in conjunction with the trouble analysis charts. All the test points noted in the trouble analysis charts are indicated on the schematic diagrams in this section. Also contained in section VII is a complete set of waveform diagrams (photographs) which appear at the various designated test points.

TROUBLESHOOTING

Following are some failures which have occurred in the AN/UPM-32 test set. The symptoms and the methods of isolating the trouble are described. Of course, this is not a complete list of troubles that have occurred, but these particular failures are the ones most likely to be encountered.

There is no intent here to imply that the test set is unreliable; experienced technicians have proven that it is reliable when operated properly. However, it is a characteristic of the AN/UPM-32 test set that mixer crystal can be damaged by improper manipulation of the test set controls. Consequently, this is the most common failure.

Failure of the Mixer Crystal

Failure of the mixer crystal is indicated by an absence of the bell pattern on the scope when the function switch is in the MIXER position and the SIGNAL WIDTH control is in the MIN position (fully counterclockwise).

In performing the isolation procedure, the technician should check that a SET POWER reading can be obtained with the function switch in the EXT MOD position by manipulating the REFLECTOR knob and POWER SET knob. If a SET POWER reading can be obtained, the klystron oscillator is all right and the trouble is most likely the mixer crystal.

Failure of the RF Switch

RF switch failure is indicated by inability to balance the meter. That is, the METER BALANCE control cannot be adjusted for a ZERO SET reading, or the ZERO SET reading will not hold while calibrating the test set to make a receiver sensitivity check.

In performing the isolation procedure, place the function switch in the PWR-FREQ METER position and rotate the REFLECTOR control back and forth between its limits. If the meter needle moves, the RF switch is not operating properly. For this check, make sure that the POWER SET knob is set approximately 6 turns clockwise and the SIGNAL WIDTH control is fully clockwise for maximum signal width. This failure cannot be repaired at the squadron level.

Failure of the Klystron Oscillator

Klystron oscillator failure is indicated by an absence of the bell pattern on the scope when the function switch is in the MIXER position and the SIGNAL WIDTH control is in the MIN position (fully counterclockwise).

In performing the isolation procedure, check that a SET POWER reading can be obtained with the function switch in the EXT MOD position by manipulating the REFLECTOR knob and POWER SET knob. If a SET POWER reading cannot be obtained, the klystron tube,is probably bad; however, before changing the klystron, make the check for a shorted crystal diode clipper as given below.

Failure of Crystal Diode Clipper CR-105

Failure of clipper CR-105 is indicated by an absence of the bell pattern on the scope when the function switch is in the MIXER position and the SIGNAL WIDTH control is in the MIN position (fully counterclockwise).

In performing the isolation procedure, place the function switch in the EXT MOD position and check for a negative klystron plate voltage at the ungrounded terminal on CR-105. This voltage should be variable by turning the REFLECTOR knob. If the voltage is very low or zero, the trouble is probably a shorted CR-105; however, before changing CR-105, check the output of the negative voltage power supply. A shorted CR-105 usually results in a damaged klystron.

Sticking Attenuation Plungers

Sticking of the attenuation plungers is indicated by inaccurate transmitter power and/or receiver sensitivity measurements.

In performing the isolation procedure, visually check that the two attenuation plungers operated by the ATTENUATION knob move freely. Also, visually check that the two attenuation plungers operated by the HI-LO ATTENUATION control operate freely. If any are found to be sticking, apply a light oil very sparingly. Excessive oil will collect dust and eventally the situation will be further aggravated.

STANDING WAVE MEASUREMENT

A transmission line which is not terminated in its characteristic impedance is subject to a condition known as standing waves. Reflection of energy at the load end of the line gives rise to a wave that travels toward the generator end. This reflected wave varies continuously in phase in much the same way that the incident wave varies in phase. At points a half-wavelength apart, the two waves are exactly in phase and the voltage is maximum. At points a quarter-wavelength from the maximums, the two waves are in continuous opposition, leading to voltage nodes. Since the amplitude at such points is readily measured, it is convenient to call the ratio of maximum to minimum voltage the voltage standing wave ratio (VSWR). A similar ratio of currents will have the same value. A high SWR indicates a poor impedance match, and a low SWR indicates a good match. An SWR of 1:1 is optimum.

The measurement of VSWR has proved useful for the purposes of repair, preventive maintenance, checking, and making adjustments. In

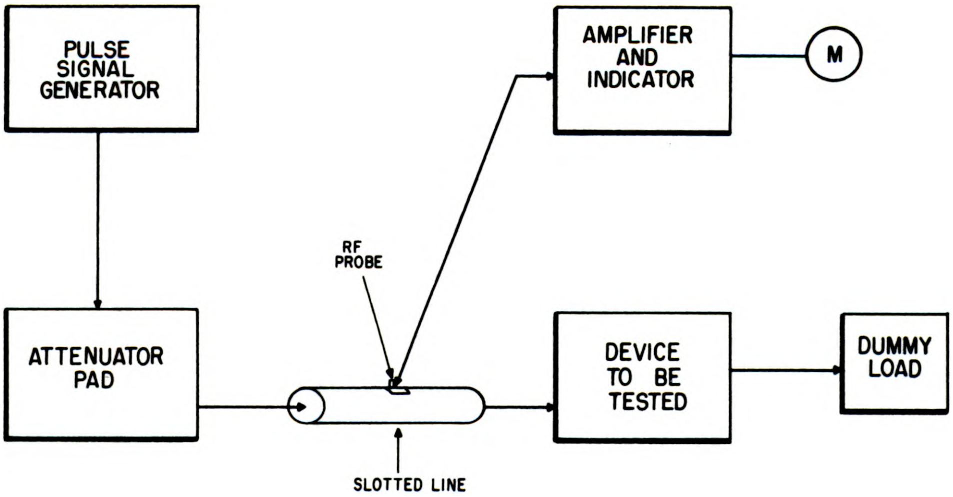

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Figure 16-10. –SWR test setup.

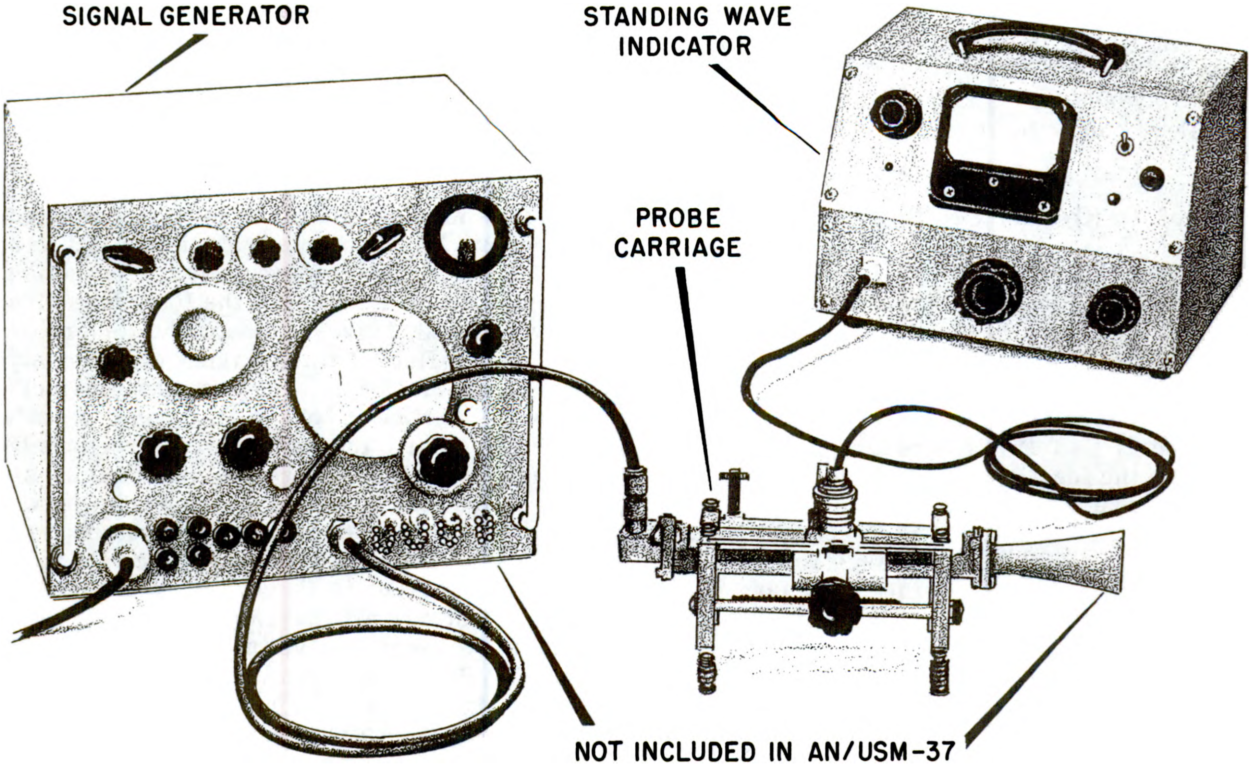

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Figure 16-11. –AN/USM-37 test setup.

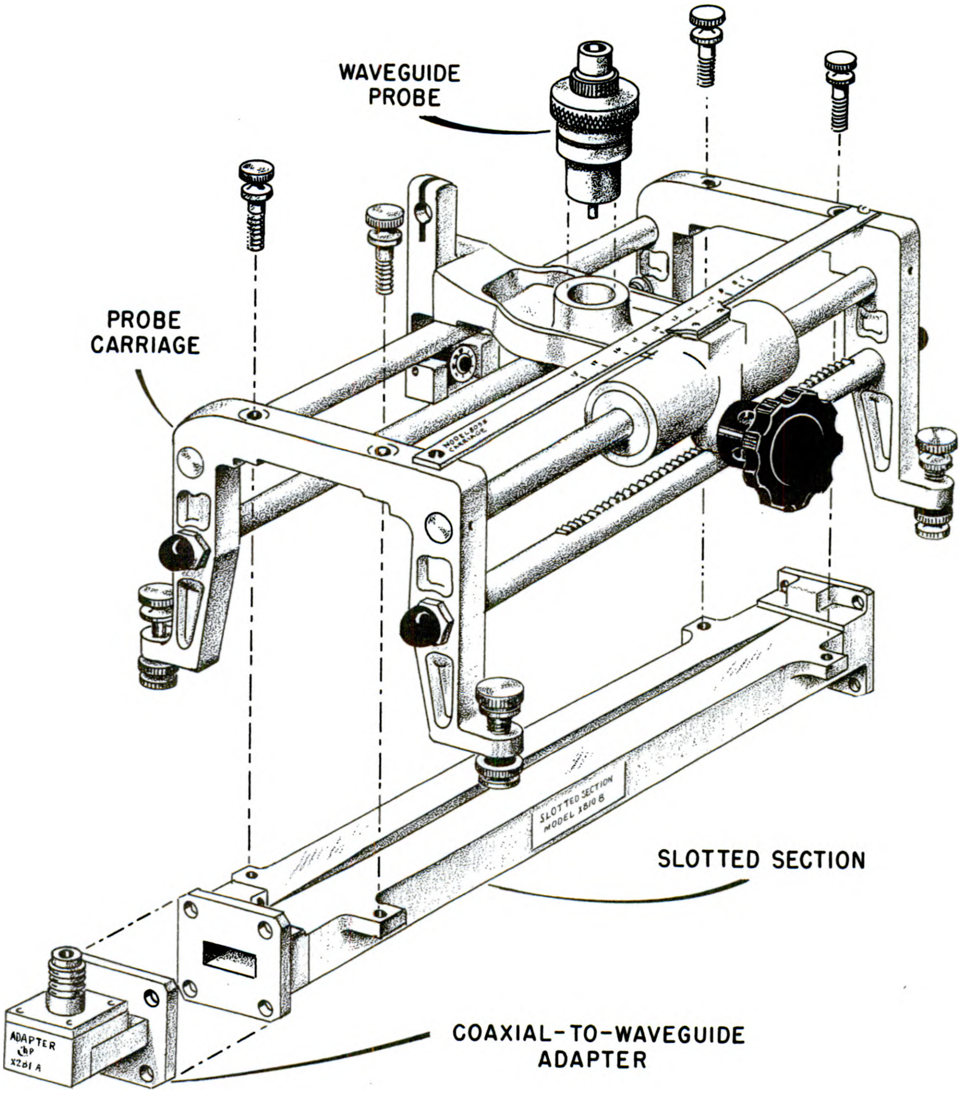

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Figure 16-12. –Probe carriage and slotted section assembly.

radar work, a low SWR is maintained for the following reasons:

1. Reflections in the line cause magnetron pulling and could result in faulty pulsing (this effect is more pronounced when the line is long compared to a wavelength).
2. Arc-over may occur at maximum voltage points.
3. Hot spots may occur in the line, and may lead to mechanical breakdown.

In radar maintenance, SWR measurements are useful for the following reasons:

1. Defective RF line components may be located by checking the SWR of each component or by substitution.

2. Radars with RF tuning adjustments may be adjusted with the aid of SWR test equipment.

Figure 16-10 shows a typical setup for testing SWR.

STANDING WAVE INDICATOR

Standing Wave Indicator AN/USM-37 is a laboratory quality test set for use in making accurate standing wave measurements in waveguide and coaxial systems over the frequency range from 3.0 to 12.4 kilomega Hertz. The test set includes two precision slotted waveguide sections, a slotted coaxial section, a voltage sampling probe, a probe carriage, a standing wave indicator, adapters, and cables. Figure 16-11 shows the two main components–the standing wave indicator and the probe carriage and slotted section assembly.

The measurement of SWR consists of setting the probe at a position of maximum voltage and then setting the gain of the standing wave indicator so that a reading of 1.0 is obtained at this position. The probe is then moved along the line until a minimum voltage point is reached. The SWR can then be read directly from the standing wave indicator scale. Although this is a basic method of making SWR measurements, in many cases it will be sufficient as this is a direct measure of mismatch of the load. More sophisticated tests can be made with this instrument, but they are mostly associated with design and development.

Wavelength measurement can be made by measuring the exact distance on the scale between 2 nulls. The most common use of the SWR indicator by the AQ will most likely be to check the match of rotating joints in antenna waveguides.

Instruction Book for Indicator, Standing Wave, AN/USM-37, NavShips 92036, contains detailed instructions for the use, operation, and maintenance of the USM-37.

MAINTENANCE

Since the slotted sections and adapters are not considered repairable, maintenance is limited to the probe carriage, the standing wave indicator, and the waveguide probe. Figure 16-12 shows an exploded view of the probe carriage and slotted section.

All tubes and components in the standing wave indicator may be replaced by identical parts with no further adjustments except as follows:

1. When replacing V1 (a voltage amplifier), select a tube that does not exhibit microphonics. Otherwise slight physical shocks will cause the meter pointer to swing or jump when the instrument is tapped with a finger.
2. When replacing tubes in the voltage regulator, the voltage should be checked and adjusted if necessary.
3. The meter should be adjusted so it reads ∞ (infinity) with the power off.
4. Components in the 1-kHz filter may be replaced by parts having identical electrical characteristics. Frequency adjustments to the 1-kHz filter are not critical. However, a trimmer capacitor is provided for minor frequency adjustments and is accessible through a hole in the top of the filter housing.
5. Following parts replacement of the 1-kHz filter or installation of a new filter, the effective Q of the amplifier should be checked as described in the equipment manual.
6. When failure occurs in the SWR DB switch, the switch should be replaced by a complete unit including the connecting cables. Heating and twisting of the precision resistor leads in the switch can premanently change their resistance and should be attempted only by technicians skilled in this type of work.

Particular care should be taken to retain the original grounding of the cable shields. Otherwise excessive noise, hum, or spurious oscillations may occur.

The probe carriage is a precision instrument designed for very high accuracy of probe positioning and travel. With careful handling, average use will result in no appreciable wear and replacement of parts should not be necessary.

The carriage is lubricated before leaving the factory but may require periodic lubrication as described in the equipment manual. Keep in mind that the carriage has components that are machined to tolerances of 1/10,000 inch and must be protected from rough handling and the possibility of machined surfaces being marred. Do not attempt adjustments, loosening, or tightening of the carriage assembly except as described in the manual.

The waveguide probe requires no maintenance other than possible crystal diode or crystal holder replacement.

ECHO BOXES

An important part of the work of the AQ involves performing tests to determine the operating characteristics of aviation fire control radar sets. The following section, related to the general principles of radar operation, is a

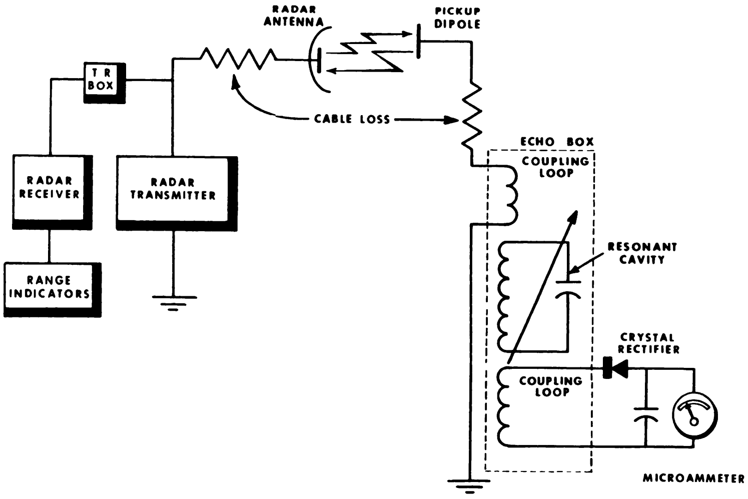

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Figure 16-13. –Circuit for echo box tests.

brief discussion of the use of a device which is often employed for making specific tests of the overall performance of a radar installation.

Under field conditions it is cometimes difficult to check the operation of radar equipment because of the absence of standard signals. However, many recently developed radar systems have built-in test (BIT) circuits. The use of normal return signals is undesirable for purposes of adjustment and measurement because these signals vary considerably with atmospheric conditions and with the nature of the physical surroundings. A device which is frequently used to supply standard reference signals is the echo box.

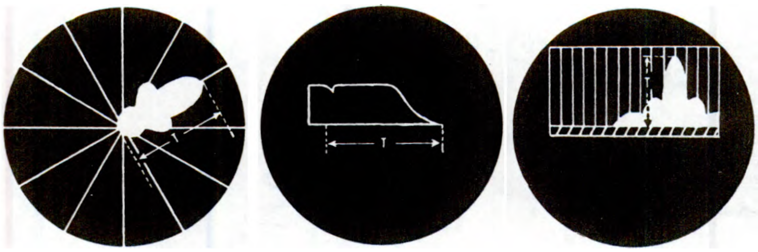
An echo box is a tunable resonant cavity which has a very high Q. The cavity is equipped with coupling loops, either a dipole or a coaxial horn antenna, a crystal detector, a microammeter, and several sections of transmission line. The cavity is tuned by means of a movable plunger which is mechanically connected to a calibrated tuning dial. The echo box receives energy from the radar transmitter either by use of a pickup dipole (or horn) or by connection through a cable to a directional coupler in the transmission line of the radar set.

Echo boxes are used in measuring the overall performance of radar sets, in making spectrum graphs of magnetrons, for measuring the relative power output of radar transmitters, and for checking the frequency of the transmitter and of the local oscillator.

The basic circuit for making echo box tests is shown in the block diagram of figure 16-13.

In measuring the overall performance of radar sets, some of the energy generated by the radar transmitter is picked up by the directional coupler or the pickup dipole and applied to the echo box. This energy excites oscillations in the echo box which persist for some time after the end of the radar pulse. These oscillations gradually die out because some of the power is radiated back to the radar set and the rest of it is dissipated in the echo box cavity and in the output meter circuit. The part of the energy that is fed back to the radar antenna causes a signal to appear on the radar indicator.

RINGING TIME is defined as the time between the end of the transmitted pulse and the instant the returned energy from the echo box falls below the minimum value required to give an indication on the radar indicator. The ringing time duration depends upon the power output of the transmitter and the sensitivity of the receiver. The longer the ringing time, the better is the overall performance of the system. Each radar set has a minimum performance ringing time, and this value provides a standard for use in checking the operation of the set. The value of the minimum ringing time for a



PPI SCAN A SCAN B SCAN

T=RINGING TIME

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Figure 16-14. —Ringing time indications.

particular radar can be found in the appropriate manual of operating instructions.

Figure 16-14 illustrates three typical ringing time indications similar to those in overall performance checks made with echo boxes.

An echo box is often used in making a spectrum graph of a transmitter's output. Each time a radar transmitter generates an RF pulse it produces energy in the form of electromagnetic waves. Not all of these waves are of the same frequency. Some of the energy is radiated at the frequency to which the transmitter is tuned and the remainder is distributed. in frequencies which are higher and lower than the tuned frequency. A spectrum graph showing the values of the frequencies present and their relative strength can be made by tuning the echo box across the entire range of frequency values in the output of the transmitter. The readings of the output meter in the echo box are plotted against frequency values in the spectrum which are read from the calibrated dial of the instrument. A radar transmitter in satisfactory condition gives a spectrum graph which is a peak with the sloping sides symmetrical and well defined minimum values. A curve without well defined minimum values indicates that the transmitter output is frequency modulated during the pulse as explained previously.

The echo box can be used to measure the relative power output of radar transmitters. The amount of energy delivered to the resonant cavity of the echo box depends on the average power of the radar pulse, the pulse length, the amount of loss in the directional coupler or pickup dipole, and the amount of loss in the connecting cables. The echo box is tuned to give a maximum reading of the output meter. The meter coupling circuit is then adjusted so that the maximum reading falls on the approximate center of the scale, and this value is recorded for use as a reference. After adjustments on the transmitter are made, the readings of the echo box output meter are compared with the reference value to determine the effects of the adjustments on the output power.

Multiple moding, which is an abrupt and irregular jumping from one frequency to another, sometimes occurs in microwave radar equipment. This effect is readily detected with the echo box. The indication of multiple moding is an erratic ringing time pattern containing several background noise traces in the pattern.

The transmitter frequency and the frequency of the receiver local oscillator can be measured by using the echo box as a wavemeter. In addition to these checks, the device can be used in measuring the signal to noise ratio for testing the operation of the automatic frequency control, for measuring the TR box recovery time, the receiver recovery time, and the amount of loss in transmission lines. For these tests and measurements, the instruction manual for the particular echo box in use must be consulted.

DUMMY LOAD

When testing radar transmitters in the microwave frequencies, it is frequently necessary to dissipate the transmitted RF power in a test or "dummy" load. Many variations exist in the type of load used for this purpose; the only requirements being that the dummy load have the capability to dissipate the required amount of

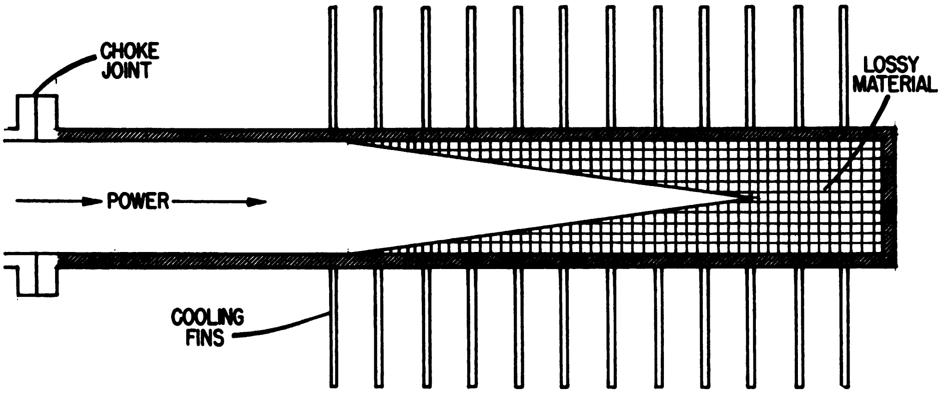

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Figure 16-15. –Dummy load.

power. It must also present a suitable impedance to the source of energy and not set up reflections and standing waves which might pull and damage the transmitter.

The termination of a waveguide system at microwave frequencies is normally done with an attenuator, as illustrated in figure 16-15, in which the walls of the waveguide are lined with lossy material. The lossy substance is mounted so that the height of the guide (but not width) is tapered as illustrated. With this type attenuator the attenuation per unit length is increased as the RF wave penetrates into the lossy section. This results in a reduction of the length required in order to maintain a low standing wave ratio, and results in a more even distribution of the generated heat. The lossy material normally consists of powdered graphite impregnated in a cement binder and cast into the proper shape within the guide. In addition, the attenuator normally has external radiating fins which are used to assist in dissipating the heat. Dummy loads constructed in a manner as illustrated in figure 16-15 have a high power handling ability, a good standing wave characteristic, and are built for wavelengths as short as 1 cm.

The maintenance required on a dummy load consists mainly of cautious handling. Do not drop, strike, or otherwise mistreat the unit so as to bend the cooling fins, break the lossy material, or damage the choke joint connection and O-ring seal.

RANGE CALIBRATOR

The range calibrator discussed in this chapter is the Radar Test Set AN/UPM-109. With this instrument a video target can be simulated with accurately known range, range rate, and range acceleration characteristics for use in testing range tracking radars. This video may be used to modulate an RF signal which may be space coupled to the radar being tested. Also, the bandwidth of the antenna positioning servos may be approximated using this test set.

The outstanding characteristic of the test set is the straightforward, understandable nature of the tests which it may be used to perform.

The test set comprises eight plug-in assemblies in a main frame assembly which is housed in a combination case. The cover provides storage space for loose cables and the instruction manual. When the cover is installed properly, the test set is completely protected from moisture and dust. If desired the test set can be used leaving it in its case, or it can be removed from the case and mounted on a rack. Cooling is accomplished by a blower mounted on the front panel. Power required to operate the test set is 115 volts a.c. regulated to ±10 percent at 50 to 420 Hertz. Ambient operating temperatures are -45° C to +55° C.

Since the AN/UPM-109 is a general purpose piece of test equipment, it would be impossible for one step-by-step procedure to serve for all possible equipments for which it might be used.

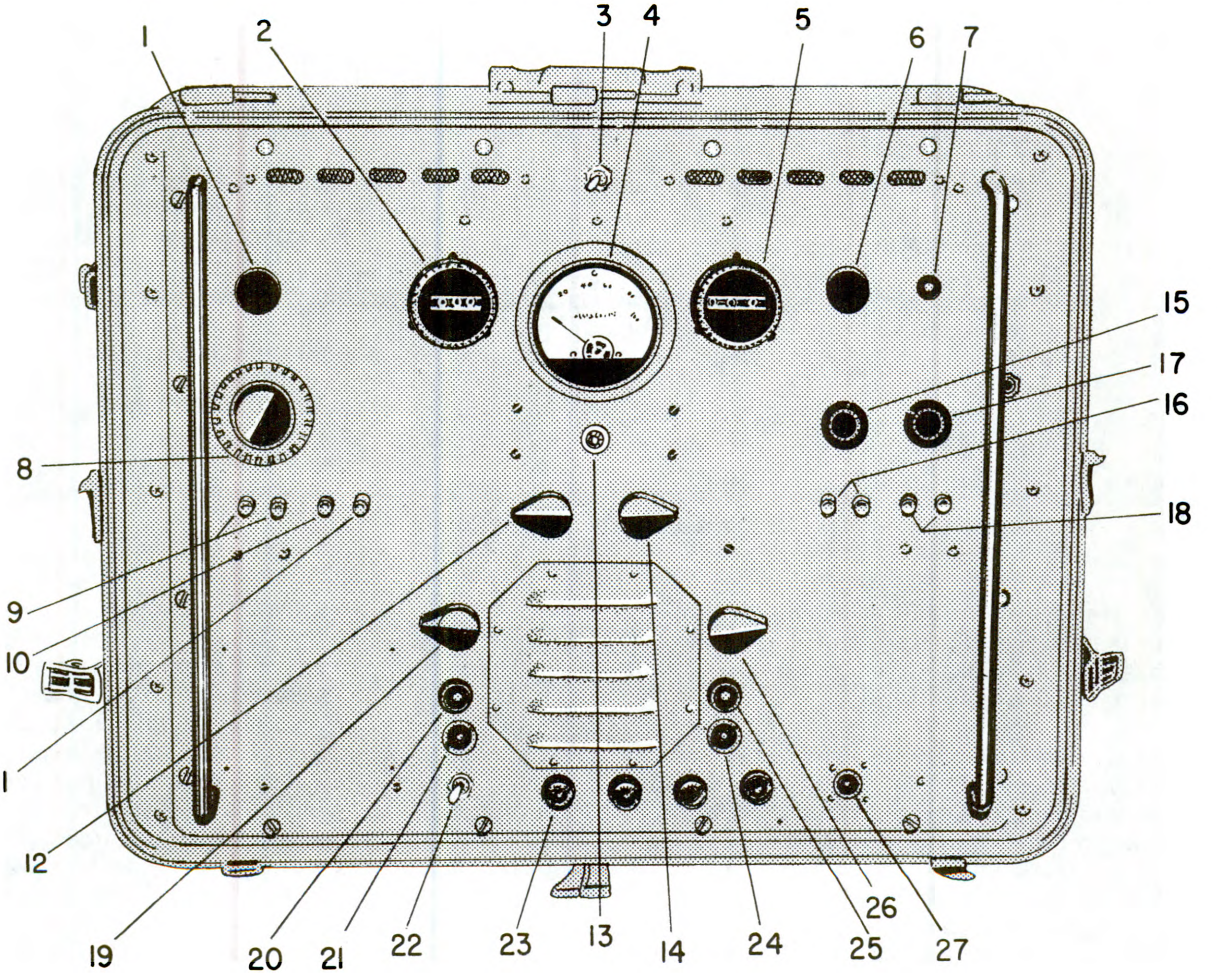

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Figure 16-16. —Radar Test Set AN/UPM-109

Therefore, a general description of its capabilities and functions is given, followed by a few suggestions and comments of a somewhat more specific nature concerning the various tests which are possible.

OPERATING CONTROLS AND INDICATORS

Complete operation of the test set is attained through use of controls, indicators, and connectors located on the front panel. For a description of these controls, indicators, and connectors, see figure 16-16 and table 16-3.

CAPABILITIES

By simulating a target with known range characteristics, important operational checks can be performed as described in the following paragraphs.

Range Calibration

Continuously variable range calibration data is available in two ranges: 0 to 1, 000 and 0 to 100, 000 yards, with an accuracy of ± 1/4 percent of full scale.

Range Rate Calibration

Continuously variable range rate calibration data is available from 0 to 500 knots, with an accuracy of ±1/2 percent of full scale. Detailed capabilities are as follows:

1. A constant range rate tracking test may be used to establish the maximum opening and closing rates the radar can accommodate.

Table 16-3.-Controls, indicators, and connectors.

Number	Control, indicator, or connector	Function
1	AM LEVEL control	A variable control to adjust the modulation level for either external or internal modulation of the output target pulse.
2	RANGE YARDS control and indicator	A variable control and counter dial to control and indicate the range of the simulated target.
3	METER EXPANSION control	A spring return toggle switch which, when operated, increases the meter sensitivity by approximately 10 times normal. It is used in conjunction with the ZERO HOLD control as a means of observing drift of target position when the TARGET FUNCTION control is in the RATE position and the TARGET RATE/ACCEL selector is in the HOLD position.
4	Range yards meter	A meter which provides a constant indication of target position.
5	RATE/ACCEL control and indicator	A variable control and counter dial to control either the target rate or target acceleration. The counter dial indicates in knots during "rate" operation and in G's during "accelerate" operation.
6	PRETARGET RANGE control	A manual adjustment for the interval between the target and pretarget pulses. Used only with an external trigger output.
7	TARGET INTERRUPT control	A spring return toggle switch which, when operated, disables the target pulse.
8	INT PRF control	A variable control with a calibrated dial enabling fine setting of internal PRF.
9	EXT TRIGGER positive and negative connectors	Two connectors used for applying to the test set either positive or negative external trigger inputs.
10	EXT PROGRAM connector	A connector used to apply an input to the test set for range programing.
11	EXT AM connector	A connector used to apply an input to the AM LEVEL control for modulation of the target pulse from an external source.
12	TARGET FUNCTION control	A three-position switch which selects the functions indicated in the following positions: 1. RATE 0 - 5,000 KNOTS - Provides a moving target, the velocity of which is determined by the setting of the RATE/ACCEL control and the direction of which is determined by the TARGET RATE/ACCEL control. 2. RANGE YARDS - Provides a stationary target the position of which is determined by the RANGE YARDS control. 3. ACCEL 0 - 50G - Provides a moving target, the acceleration of which is determined by the setting of the RATE/ACCEL control.

Table 16-3.—Controls, indicators, and connectors—Continued.

Number	Control, indicator, or connector	Function
13	ZERO HOLD control	A screwdriver adjustment used to compensate for long term drift which affects the calibration of the RATE/ACCEL dial. It is used in conjunction with the expanded meter scale.
14	TARGET RATE/ACCEL control	A three-position switch which in the IN position selects a decreasing target range and in the OUT position selects an increasing target range. These positions are used for either rate or acceleration operations. When placed in the HOLD position and with the TARGET FUNCTION control at the RATE position, the target will stop and hold at the range indicated at time of switching. When the TARGET FUNCTION control is at the ACCEL position, the HOLD position holds the velocity and direction of the target present at time of switching until the target has moved off the target scale. The acceleration feature is only provided in the 100,000-yard operation.
15	TRIGGER/PRETARGET AMPLITUDE control	A control used to adjust the output trigger pulse amplitude.
16	TRIGGER OUT positive and negative connectors	Two connectors which provide positive and negative trigger output pulses.
17	TARGET AMPLITUDE control	A control used to adjust the output target pulse amplitude.
18	TARGET OUT positive and negative connectors	Two connectors which provide positive and negative target output pulses.
19	MAX RANGE control	A two-position switch to select either 10,000 yards or 100,000 yards range as maximum test set output.
20	OPERATE indicator	A light which illuminates when test set is operational.
21	OVEN indicator	A light which, when illuminated, indicates the operation of heaters in an enclosure containing circuit elements requiring constant temperature control.
22	POWER control	A two-position switch which, when in the ON position, applies primary power to the test set.
23	5-ampere fuse	A safety device in the primary power circuits to protect the test set against overloads.
24	BLOWER CYCLE	A light which illuminates when the blower is on.
25	OVEN FAILURE indicator	A light which illuminates when there is a failure in the oven heater circuit.

Table 16-3.–Controls, indicators, and connectors–Continued.

Number	Control, indicator, or connector	Function
26	MODE selector	A four-position switch which selects the operating conditions indicated in the following positions: 1. EXT TRIGGER INT AM - synchronizes target and pretarget pulses with negative or positive pulses applied to the EXT TRIGGER connectors. Allows target modulation at frequency set on INT PRF dial. (PRF operates from 25 to 500 Hz.) 2. EXT TRIGGER EXT AM - same as EXT TRIGGER INT AM position except external modulation input required if target modulation is desired. 3. INT PRF 25 - 500 - operates target and trigger pulses at internal PRF as selected by INT PRF dial, within 25 - 500 PPS. Permits external modulation input for target. 4. INT PRF 250 - 5000–same as INT PRF 25 - 500 position except for change in INT PRF dial range to 250 - 5000 PPS.
27	Power in Connector	1. Receptacle for connecting primary input power.

2. A velocity step rejection test may be used to determine the response of the radar to abrupt changes in velocity.

3. A rate memory test may be used to establish that memory circuitry allows "tracking" for an interval of time after loss of target.

Range Acceleration Calibration

Continuously variable range acceleration calibration data is available from 0 to 50 G's with an accuracy of ±5 percent (available on the 100,000-yard range only). Detailed capabilities are as follows:

1. Tracking ability, during constant acceleration, establishes the maximum range acceleration and deceleration rates the radar can accomodate.

2. Acceleration tolerance test determines the tolerance of the memory function to a target which has range acceleration as well as velocity.

3. The functional test for tracking ability with a maneuvering target may be made employing a programed simulated maneuver to the EXT PROGRAM jack.

FUNCTIONAL DESCRIPTION

The target generated is a 0.6-μsec pulse (measured at the half power points) with an amplitude which can be adjusted from 0 to 65 volts.

External Sync

The trigger from the radar being tested (9, fig. 16-16) may be used as a synchronizing pulse, inserting it at the EXT TRIGGER jack (observing the proper polarity) and using either of the two EXT TRIGGER positions of the MODE switch (26, fig. 16-16). The test signal used to simulate a target may be either RF or a video signal. (See fig. 16-17 and fig. 16-18.)

Internal Sync

The trigger pulse generated within the test set may be used as a synchronizing pulse for the radar by connecting the output of the appropriate polarity from one of the TRIGGER OUT jacks to the radar. The amplitude of this trigger is controlled by the TRIGGER/PRETARGET AMPLITUDE control (15, fig. 16-16). The PRF is controlable by the INT PRF knob (8, fig. 16-16). The control has a range of 25 to

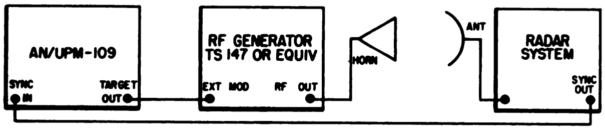

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Figure 16-17. –Equipment interconnection using space (RF) coupling.

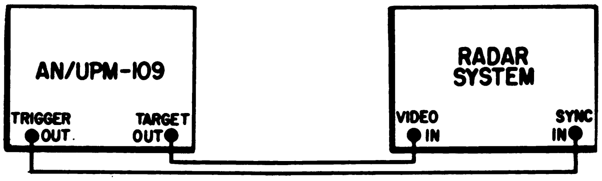

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Figure 16-18. –Equipment interconnection using video targets directly.

500 or 250 to 5,000 PPS, depending on the position of the MODE switch.

MODE Switch

The MODE switch selects one of four sync positions, two each for external and internal. When external sync is selected, the signal appearing at the TRIGGER OUT jacks is called the PRETARGET pulse. This pulse is particularly valuable as it can be used as an oscilloscope synchronizing pulse. The position of the pulse, in time, is adjustable so it is in coincidence with the target or at any range prior to the target up to 600 yards on the 10,000-yard range or 6,000 yards on the 100,000-yard range. This adjustment is provided by the use of the PRETARGET RANGE knob (6, fig. 16-16).

Function Selection

The TARGET FUNCTION switch (12, fig. 16-16) is used to select proper operating function of the test set. When the switch is in the RANGE YARDS position, a target with a fixed range is selected. The range of this target is controlled by the RANGE YARDS control (2, fig. 16-16). The range can be read directly from the indicator dial seen through the small window in the knob. The maximum indication of the dial is 9,990 yards. The outer shell of the control knob can be turned to interpolate the fourth digit.

With the switch in the RATE 0-5,000 KN position, the target wil move with a constant speed, corresponding to the setting of the RATE/ACCEL control (5, fig. 16-16) and the setting of the TARGET RATE/ACCEL switch, which must be either in the IN or OUT position (14, fig. 16-16). If the TARGET/ACCEL switch as in the hold position, no target motion is allowed.

With the switch in the ACCEL 0-50G (100,000-yard range) position, the target accelerates at a constant rate, its direction and amount of acceleration being controlled by the same controls that governed the rate in the RATE 0-5,000 KN position of the switch.

Zero Hold Adjust

Since a high gain d-c amplifier (operational amplifier) is used, it is necessary to check for drift and readjust for zero drift quite frequently. To make this adjustment, select a target in the midrange, placing the TARGET RATE/ACCEL switch in the hold position. The TARGET FUNCTION switch is placed in the RATE 0-5,000 KN position. If there is any drift of the target position indicated on the meter (4, fig. 16-16), the zero hold potentiometer located just under the meter must be adjusted to balance it out. The final adjustment must be made with maximum meter sensitivity. This is accomplished by operating the meter expansion switch, located just above the meter. It may be necessary to repeat the procedure several times, as the meter will probably drift off scale before the adjustment is completed. This adjustment must be made accurately, or target position will drift, and range rate and acceleration values will be in error proportionately.

Servo Bandwidth Measurement

By amplitude modulating the video target pulse in the AN/UPM-109 at a frequency near the nutation rate of the radar antenna and feeding the RF target pulse to the radar, the bandwidth of the antenna servos may be roughly measured. The RF signal is spaced coupled to the radar antenna; for example, this is the procedure when the TS-147 is used. A reference axis is established by causing the radar to track the signal from the horn with no modulation present. By inserting a small modulation signal and varying the modulating frequency until a zero beat condition is obtained, indicated by motion of the antenna nutation axis ceasing, the nutation frequency is determined and a predetermined departure from the reference axis (for example, 6° in the azimuth plane) can be obtained. By varying the modulating frequency and leaving the level of the amplitude modulation fixed, the antenna will begin to point in an orbital path about the horn (target) at a rate corresponding to the beat difference between the nutation rate of the radar antenna and the modulating frequency. The original angular displacement reference of 6° is then reduced by one-half, to an angular displacement of 3°, by increasing the beat difference frequency. The beat frequency which produces this half-deflection amplitude will determine pass band of the azimuth servo. The same procedure is then used to determine the elevation servo pass band.

Range Calibration

For an accurate radar range voltage measurement, it is necessary to provide a target of precisely known range and measure the resulting range voltage in the radar. The problem, for the man in the field, is to get an accurate measurement of this range voltage by the choice of a reliable and accurately calibrated voltmeter. He must also keep in mind that loading effects of the meter will probably dictate the use of a vacuum tube voltmeter (VTVM) and that VTVM's are subject to drift.

For range calibration the TARGET FUNCTION switch is placed in the RANGE YARDS position. Normally the radar range zero point is first adjusted, then the range slope is set at some point near the maximum range of the sweep. It should be remembered that measurement of these two points will determine nothing about the linearity. A third intermediate point is a minimum requirement, although as many intermediate points can be calibrated as desired.

Range Rate Calibration

Since in the tactical situation the target will probably close at a rate much higher than the opening rate, it is desirable to determine the ability of the radar to track high closing rates. Tracking ability at various target velocities is discussed in the following paragraphs.

CONSTANT RATE TRACKING ABILITY.–The ability of a radar to track a target of constant velocity can be determined simply by trial and error. It is, in general, necessary to lock-on to the target after range rate has been imparted; that is, after the TARGET RATE/ACCEL switch has been moved out of the HOLD position to the IN or OUT position. The reason for this is that a large acceleration is imparted when the change is made suddenly from a fixed range target to one with constant velocity. Radars employing an acceleration gate may not remain locked-on at this time. In fact, if the acceleration gate functions properly, lock-on will not, in general, continue. However, it will be necessary to wait for the duration of any lock-on memory to elapse for the lock-on relay to deenergize.

VELOCITY STEP REJECTION.–A radar must accommodate self-noise and minor malfunctions (that is, small velocity steps) without losing track. Also, it is desirable to fail to respond to large steps, on the order of from 40 to 300 knots because such values do not tend to represent real targets. If the maximum step accommodated is about 40 knots, a considerable freedom from susceptibility to countermeasures, friendly or enemy, may be obtained. The ability to accommodate large step changes in velocity is a measure of the ease with which the range gate may be "stolen."

RATE MEMORY TEST.–The lock-on relay should not deenergize immediately on loss of target. It should remain energized for a while even though noise or CW jamming is occuring or the radar transmitter is momentarily turned off to elude a radar seeking missile.

To test this function it is necessary to allow sufficient time after lock-on to establish the memory (allow the memory capacitance to reach steady state charge). At least 15 seconds should be allowed to insure that sufficient time has elapsed after lock-on. The memory can then be measured by momentarily eliminating the target, using the spring loaded TARGET INTERRUPT switch (7, fig. 16-16), and timing the interval the lock-on relay remains in the locked-on position.

Acceleration Gate

A maneuvering target may represent a maximum change in velocity of about 2.5 G's, but chaff (window) or decoys may produce very high acceleration (or deceleration). Therefore, an acceleration gate, if designed into the radar, should allow a target range acceleration not exceeding about 2.5 G's.

Acceleration Tolerance Test

There should be some tolerance to range acceleration when range rate memory is being employed. A representative figure of 0.1 G acceleration may be inserted to test this tolerance. Of course, time must be allowed for the rate memory to be established at some rate (which may be zero) after lock-on. A waiting period of 10 seconds is adequate in atypical situation. Flipping the TARGET FUNCTION switch rapidly from RATE to ACCELERATE should not introduce an appreciable transient into the target motion; however, since the same knob is employed for both rate and acceleration functions, a really rapid changeover from RATE to ACCEL can be accomplished only at values which correspond to a common dial setting. If the switching transient is severe, the balance pot on the operational amplifier assembly may require adjustment. Further, if transients result from changes in power line voltage, adjustment of the drift pot, also on the operational amplifier assembly, maybe required. For these adjustments, consult the Service Instruction Manual for theequipment. A range rate memory circuit will employ the same time constant (as long as the associated amplifier is linear) regardless of the range rate voltage. Therefore, a check employing a rate memory at zero range rate is a valid test of the time constant of the circuit.

The test is accomplished (for zero range rate) by locking onto a fixed target and allowing about 10 seconds for circuit stabilization (rangerate memory to be established). The target is eliminated temporarily by operating the TARGET INTERRUPT switch while simultaneously introducing acceleration, and an interval of time is allowed equal to the time constant of the rate memory before releasing the TARGET INTERRUPT switch.The radar should remain locked onto the target.

Maneuvering Target Tracking Ability

It is possible to use the EXT PROGRAM jackto feed in a voltage which caused the target in the AN/UPM-109 to change its time position in accordance with an internal range voltage, the value of which is displayed on the front panelmeter, accurate to 2 percent of full scale. It is therefore possible to employ this EXT PROGRAM input as a vacuum tube voltmeter input. As such, its input resistance is 6.2 megohms and its accuracy is about 2 percent of the 100 volts full scale, or ± 2 volts.

The use of this meter as a VTVM requires that zero is selected on the RANGE YARDS counter and the TARGET FUNCTION switch is in the RANGE YARDS position.

MAINTENANCE

The air filters and the blower motor require regularly scheduled maintenance. Normally the filters are removed and cleaned at calibration periods. However, when the test set is in use in an environment where the atmosphere is heavily laden with dust particles, the filters will require cleaning between calibration periods. For complete maintenance information refer to the Service Instruction Manual for the equipment.

OSCILLOSCOPE TYPE 453

Figure 16-19 is a picture of the front, side, and rear panels of the oscilloscope discussed.

The Tektronic Type 453 Oscilloscope is a light weight, transistorized portable oscilloscope which provides the performance necessaryfor high frequency measurements. It has a single and dual-channel vertical deflection system which operates between d.c. and 50 MHz with a calibrated deflection factor ranging from 5 millivolts to 10 volts per graticule division. The two channels may be cascaded to provide a 1 millivolt minimum deflection factor. Stable triggering is provided over the entire vertical frequency response.

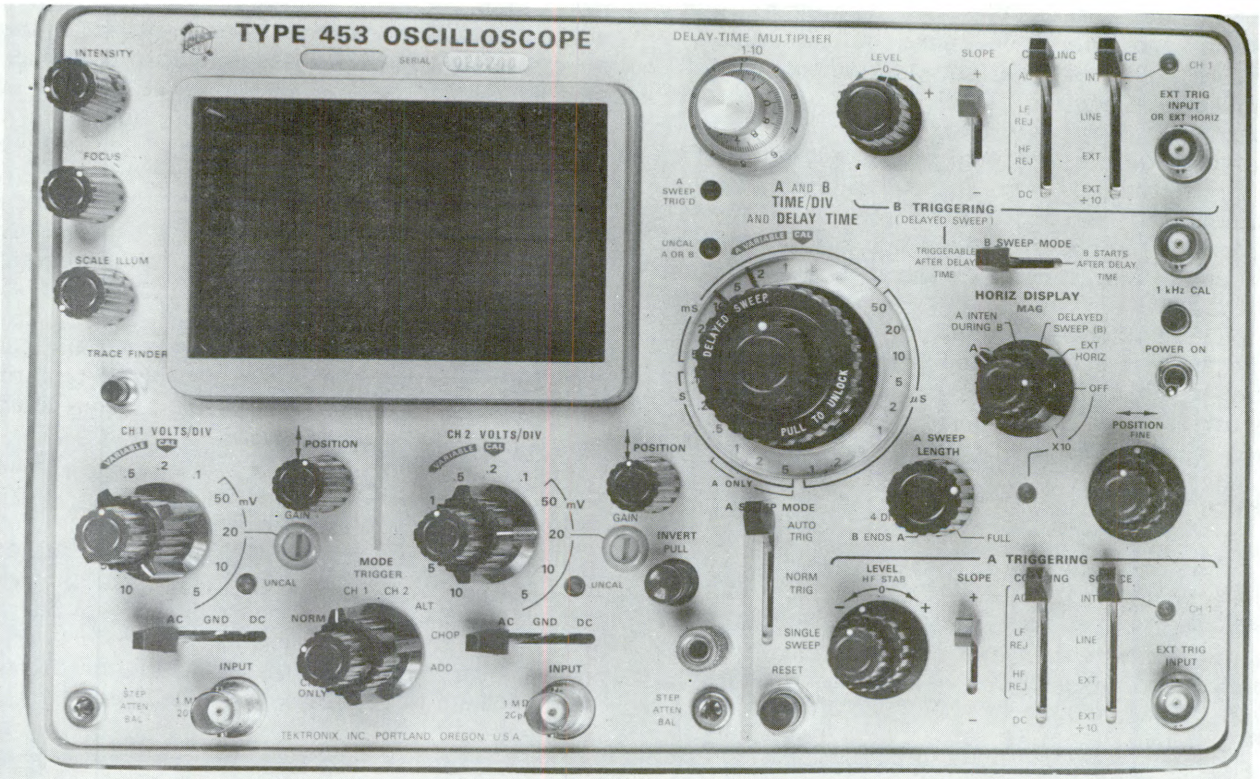
The horizontal sweep provides a maximum sweep rate of 0.1 μsec per division along with a delayed sweep feature for accurate relative time measurements.

The regulated d-c power supplies operate on either 115 volts a.c. or 230 volts a.c. with line frequencies of 45 to 440 Hz. The power consumption is approximately 100 watts.

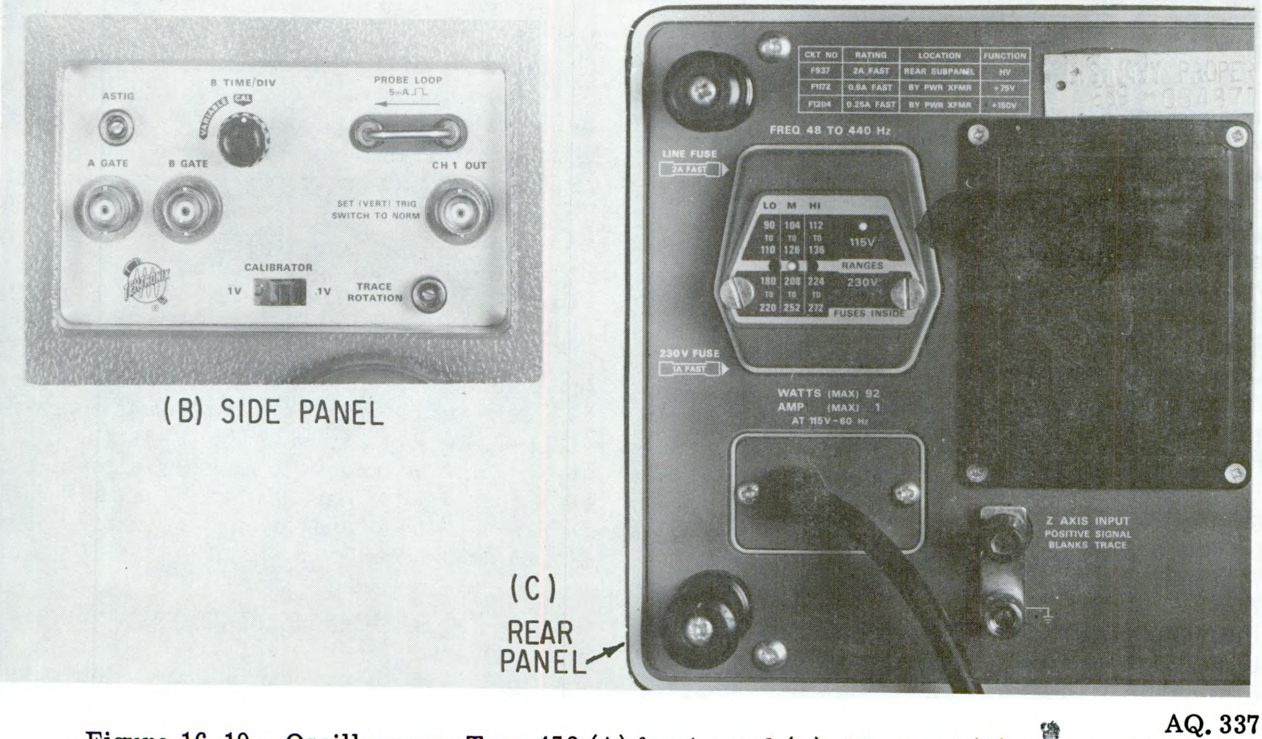
The input impedance with direct coupling is about 1 megohm in parallel with 20 pf capacitance.

PREPARING THE OSCILLOSCOPE FOR VIEWING (TRACE)

The intensity control (INTENSITY) which controls the brilliance of the sweep, varies the grid bias on the cathode-ray tube (CRT). The focus control (FOCUS) varies the potential



(A) FRONT PANEL



(B) SIDE PANEL

(C) REAR PANEL

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Figure 16-19. –Oscilloscope; Type 453 (A) front panel (B) side panel (C) rear panel.

on the focus grid. The focus and intensity interact and therefore must be adjusted together. The astigmatism adjustment (ASTIG) varies the positive level on the astigmatism grid and allows the vertical and horizontal portions of the sweep to be sharply focused at one setting of the focus control. A trace alinement control (TRACE ROTATION) provides for the rotation of the trace to a horizontal position by varying the magnetic field around the CRT. A trace finder switch (TRACE FINDER) allows the operator to decrease the overall size of the viewed signal in cases where the vertical or/and horizontal signals are so large in amplitude that they overscan the viewing area.

VERTICAL DEFLECTION CAPABILITES

The two channels (1 & 2) may be operated independently or together. Each channel has its own positioning control which moves the horizontal trace either up or down. The vertical deflection for each channel is controlled by a volts/division switch (VOLTS/DIV) and a variable control (part of VOLTS/DIV control). Each channel has its own input coupling (AC, GND, DC).

A mode selector (MODE) allows the operation of channel 1 only (CH 1), channel 2 only (CH 2), alternate (ALT) (which gives a dual trace display of signal of both channels), CHOP (which gives a dual trade display of signal on both channels), and ADD (channel 1 & 2 signals are added and the algebraic sum is displayed). The difference between ALT and CHOP is that in ALT the sweeps are changed at the end of each sweep and in CHOP the signals are switched by having a 1 μ second segment from each channel displayed at a repetition rate of 500 kHz. The channel 2 signal may be inverted at any time.

Each channel may be triggered from the signals displayed or the vertical sweep circuits may be triggered from the display on channel 1 only.

TRIGGERING CAPABILITIES

There are three sources for triggering the A and B horizontal sweeps. These are external (EXT), LINE, and internal (INT). The external trigger inputs are connected through the jacks for the appropriate sweeps. The line trigger is obtained from the power supply. The internal trigger is obtained from the trigger amplifier which receives a trigger from either the channel 1 (CH 1) vertical signal or from the normal (NORM) vertical signal after dualtrace switching has occurred. This latter trigger is a sample of the composite vertical display.

The trigger level to either the A or B sweep is adjustable in amplitude and also may be set to either the positive (+) or negative (-) slope of the trigger itself.

The type trigger coupling to each sweep is variable. The coupling may be AC, low-frequency rejection (LF REJ), high-frequency rejection (HF REJ), or DC. In the AC and LF REJ settings the d-c component of the trigger is blocked. In the AC position, frequencies below 30 Hz will be attenuated. In LF REJ, frequency components below 30 kHz will be attenuated. In the HF REJ position, signals below 30 Hz and above 50 kHz will be attenuated.

The A sweep may be triggered for either normal trigger operation (NORM TRIG), as previously mentioned, for free running operation (AUTO TRIG) (no trigger applied), or for single sweep operation (SINGLE SWEEP) in which a single sweep is presented when desired.

SWEEP CAPABILITIES

The A sweep may be operated with sweep time per division from 5 seconds to 0.1 μsec. The B sweep may be operated with sweep time per division from 0.5 seconds to 0.1 μsec. The sweep may be operated such that the entire sweep is controlled by the A sweep controls and a portion of the entire sweep is intensified by the position of the B sweep controls. When operating with a portion of the A sweep intensified and then the B sweep only control (DELAYED SWEEP (B)) is operated, only that portion of the original sweep that was intensified will be displayed. Also available is a magnified operation (X10) in which only the center $\frac{1}{10}$ of the original sweep is displayed across the entire scope face when this control is operated.

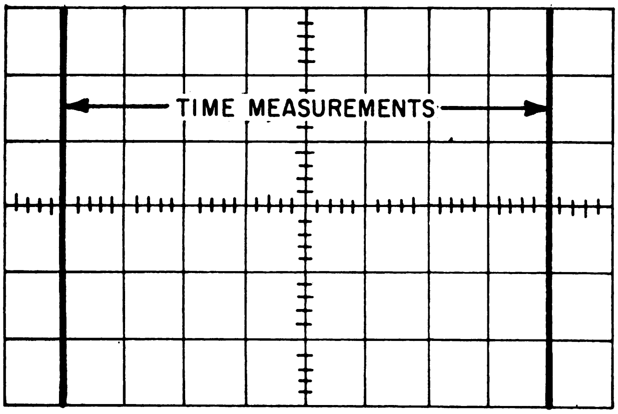
Intensity modulation of the Z-axis is available. Time markers or similar signals may be externally fed into the Z-axis (Z AXIS INPUT) and these will appear as intensity modulation on the displayed signal.

BASIC APPLICATIONS

The following applications are a few examples of what may be accomplished with the oscilloscope.

Time Measurement Area

When making time measurements the area between the first and ninth graticule lines should be used because this area is the most linear portion of the sweep. This area is shown in figure 16-20. The position control may be used to set the start of the trace (timing area) on the first graticule line and the TIME/DIV control may be used to end the timing area within the first and ninth graticule lines.



AQ. 338
Figure 16-20. -Area to be used for time measurements.

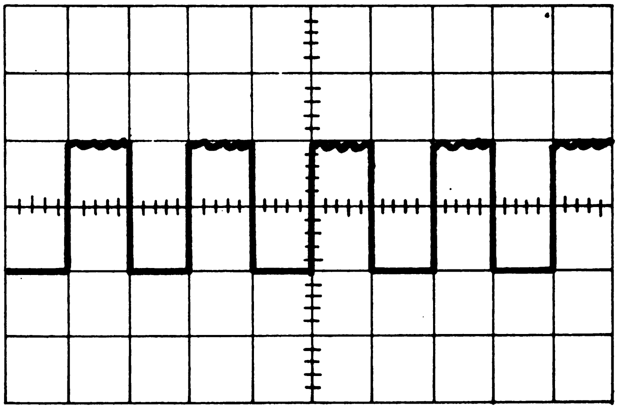
Magnification Of Sweep

A portion of a signal display may be magnified by operating the sweep control to magnification (X10). Figure 16-21 shows a signal and an investigation of the positive portion of the signal is desired. As only the center $\frac{1}{10}$ of the sweep will be magnified, the signal should be positioned as shown in figure 16-22; then when the sweep control is positioned to X10 the results shown in figure 16-23 are obtained.

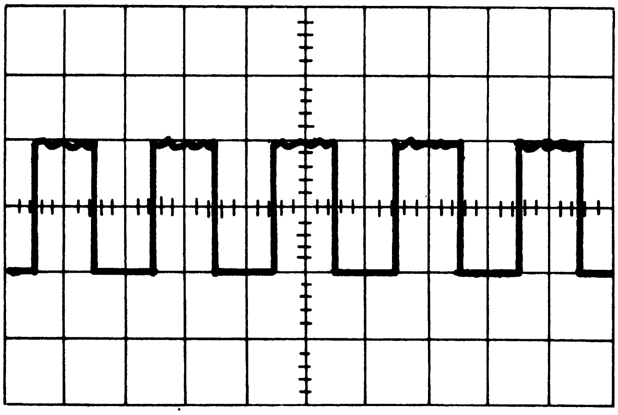
If the time per division in figure 16-22 was 0.5 μsec, the magnified sweep rate is 0.05 μsec per division. This magnified sweep rate must be used for all time measurements.

A Sweep Intensified During B (A Inten During B)

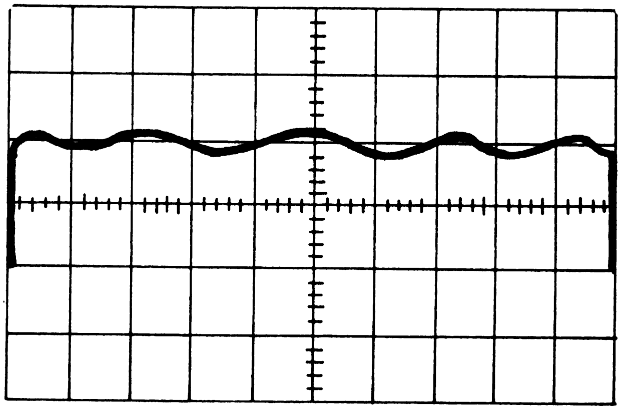
It is possible to cause a portion of a display to be intensified as shown in figure 16-24. This is accomplished by delaying the B sweep. When



AQ. 339
Figure 16-21. -Noncentered signal.

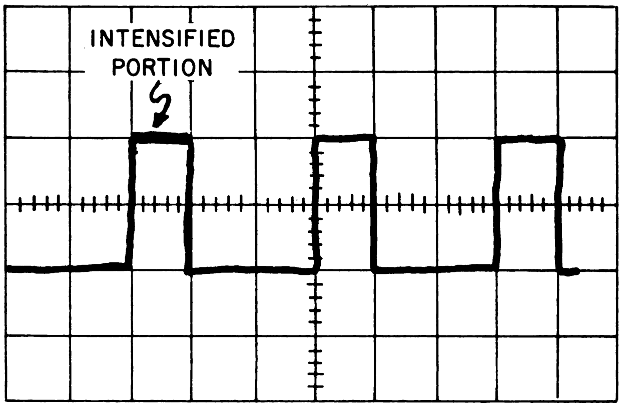


AQ. 340
Figure 16-22. -Centered signal.



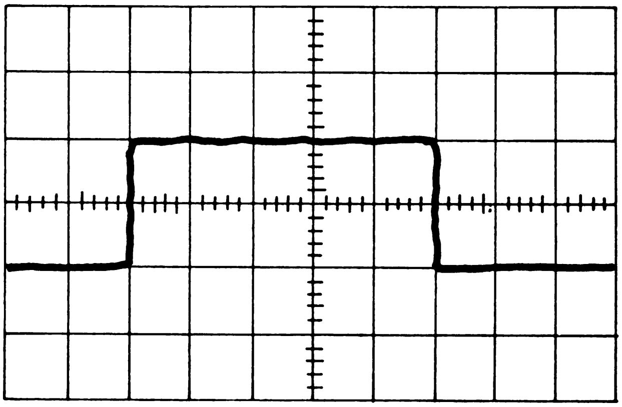
AQ. 341
Figure 16-23. -Magnified signal.

the B sweep is commenced after the delay, it will appear as an intensified portion of the displayed signal. The length of the intensified portion is determined by the sweep rate of the B sweep control (B TIME/DIV). When B sweep only (DELAYED SWEEP (B)) is operated, the intensified portion of the display in figure 16-24 will appear as shown in figure 16-25. Notice that the operations of X10 and A INTEN DURING B are similar but differ in that in the X10 operation only the center $\frac{1}{10}$ of the sweep is displayed. In the A INTEN DURING B operation, the intensified portion may be set to any portion of the A sweep. When the operation is shifted to B TIME/DIV, the intensified portion will be displayed.



AQ. 342

Figure 16-24.—B starts after delay time.

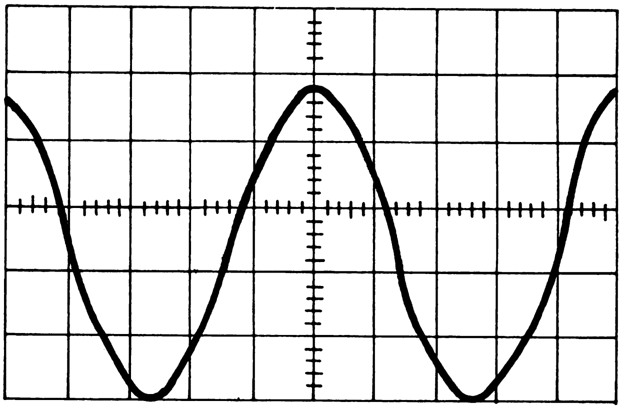


AQ. 343

Figure 16-25.—B sweep display.

Peak-To-Peak Voltage Measurements (AC)

Peak-to-peak voltage measurements of a signal, as shown in figure 16-26, are made by positioning the lower portion of the signal on the bottom graticule line. With the horizontal position control set the upper most portion of the signal on the center vertical graticule line. The number of divisions, and fractional parts, may now be counted with fair accuracy. The number of divisions are then multiplied by the vertical amplifier control (VOLTS/DIV) setting to give the peak-to-peak voltage measurement. NOTE: The VARIABLE volts per division must be in the calibrate (CAL) position for this measurement. This procedure may also be used to make measurement between any two points on a waveform.



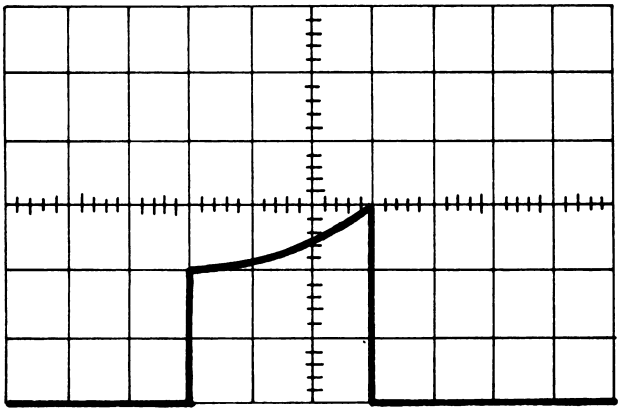
AQ. 344

Figure 16-26.—Peak-to-peak voltage measurement (a. c.).

Instantaneous Voltage Measurement (DC)

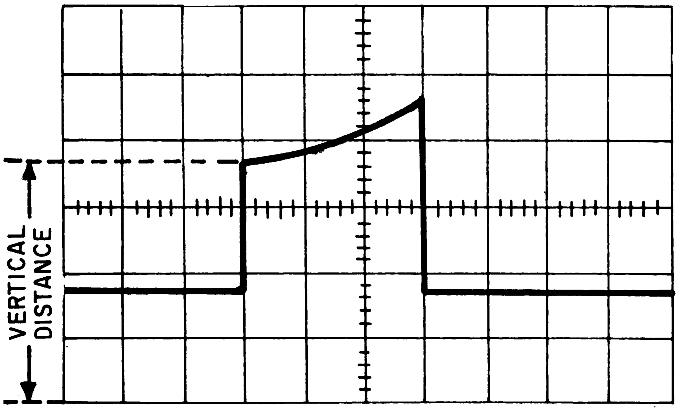
The d-c level at a certain point on the input signal may be measured by coupling the input to the sweep with the AC, GND, DC switch set to GND position. Set the bottom of the signal on the lower graticule. The vertical position control should not be moved after this setting. Switch the AC, GND, DC switch to DC. The divisions from the lower graticule to the point on the signal to be measured is multiplied by the VOLTS/DIV setting of vertical amplitude control and the product is the d-c level of the signal. This is shown in figure 16-27, which shows the signal fed in through the GND position and set to the lower graticule. Then, in figure

16-28, the same signal is fed through the DC position. The measurement is made from figure 16-28.



AQ. 345

Figure 16-27.–Lower graticule setting.



AQ. 346

Figure 16-28.–D-c measurement.

Voltage Comparison Measurements

In some cases it may be desirable to compare a signal voltage to a reference voltage amplitude. A signal of known voltage amplitude is displayed on the sweep and the variable volts per division is used to set this known signal so that the upper and lower portions fall on graticule lines. This is shown in figure 16-29. If the known voltage amplitude of the signal is 24 volts and the VOLTS/DIV switch is set on 5 volts per division then the corrected volts per division is equal to

$$\frac{\text{reference signal (voltage)}}{\text{number of division x VOLTS/DIV setting}}$$

$$= \frac{24}{3 \times 5}$$

$$= 1.6$$

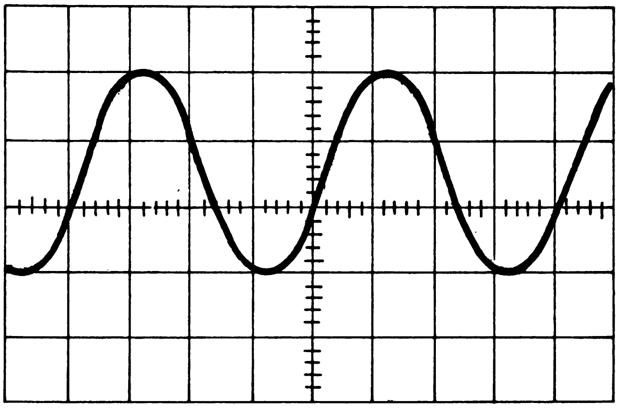
This 1.6 is referred to as the correction factor.

If a signal is now fed into the same channel and appears as shown in figure 16-30, with the VOLTS/DIV set at 2, the signal amplitude is equal to

divisions x correction factor x
VOLTS/DIV setting

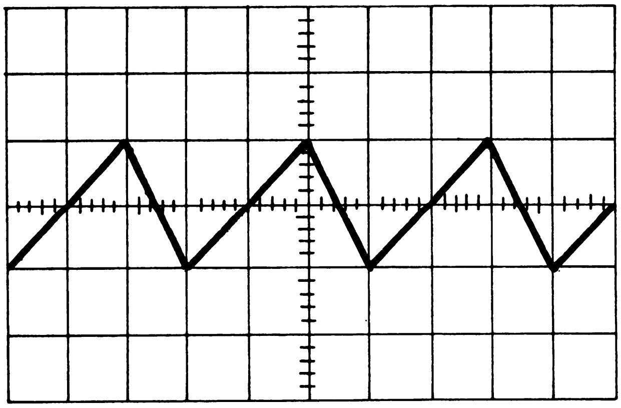
$$= 2 \times 1.6 \times 2$$

$$= 6.4 \text{ volts}$$



AQ. 347

Figure 16-29.–Reference signal.



AQ. 348

Figure 16-30.–Comparison signal.

Time-Duration Measurements

Time-duration measurements between two points on a signal may be made by setting the TIME/DIV switch so that a display of less than eight divisions between the measurement points is obtained. Set the vertical position control so that the points of measurement fall upon the center graticule. Use the horizontal position control to set the waveform, as shown in figure 16-31, so that the first point of measurement falls upon the first graticule line. The time between the two points is

TIME/DIV x horizontal divisions

In figure 16-31, if the TIME/DIV is 0.1 msec, the time between the points indicated by the dashed lines is

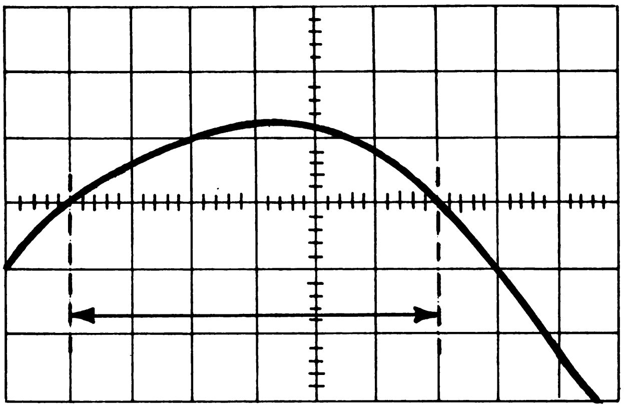
$$0.1 \text{ msec} \times 6$$

$$= 0.6 \text{ msec}$$

If sweep magnification is used (X10) then the answer must be divided by 10. That is, if magnification were used to obtain the signal display in figure 16-31, the time duration indicated would be

$$\frac{0.1 \text{ msec} \times 6}{10}$$

$$= 0.06 \text{ msec}$$



AQ. 349

Figure 16-31.—Time-duration measurement.

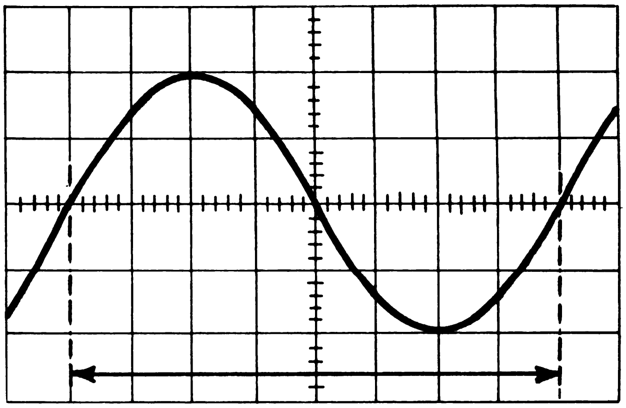
Frequency Measurements

Frequency measurements may be made by measuring the time duration of one complete cycle using the procedures previously mentioned and then taking the reciprocal of the time measurement. In figure 16-32, if the TIME/DIV is set at 5μsec, then the time duration is 5μ sec x 8 divisions which equals 40μ sec. The frequency is equal to

$$\frac{1}{\text{time duration}}$$

$$= \frac{1}{40\mu \text{ sec}}$$

$$= 2.5 \text{ mega hertzs}$$

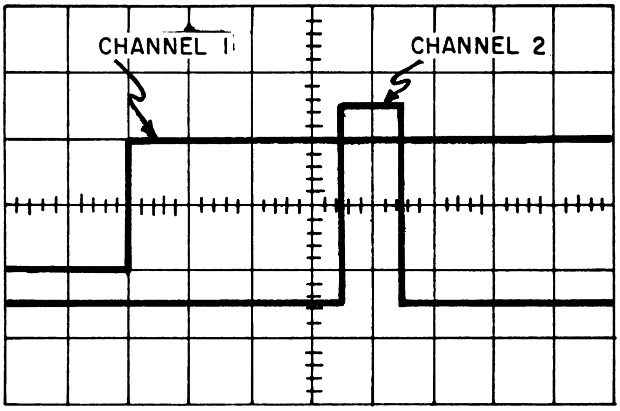


AQ. 350

Figure 16-32.—Frequency measurements.

Time-Difference Measurements

The time difference between two separate signals may be measured by displaying the signals as shown in figure 16-33. The channel 1 only (CH 1) trigger is used and the reference signal is coupled to channel 1 input and the other signal is coupled to channel 2 input. Either ALT or CHOP position of the MODE switch is used. The difference between the signals is measured in divisions, then this difference is multiplied by the TIME/DIV setting. IF X10 is used the final time difference is divided by 10. If in figure 16-33, the TIME/DIV is 50μsec and no magnification is used, the time difference between the signals is 50μsec x 3.5 divisions and equals 175μ sec time difference.



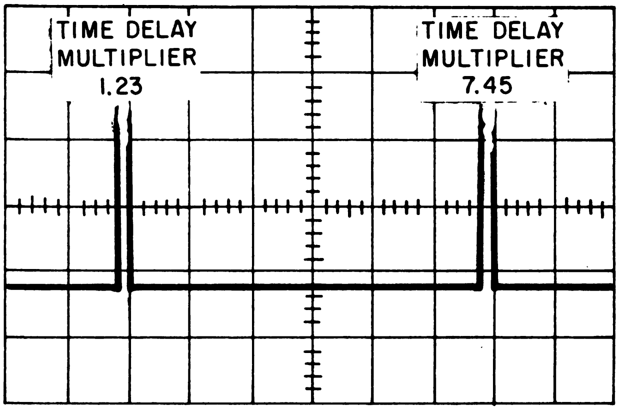
AQ. 351
Figure 16-33.–Time difference measurement.

Delayed Sweep Time Measurements

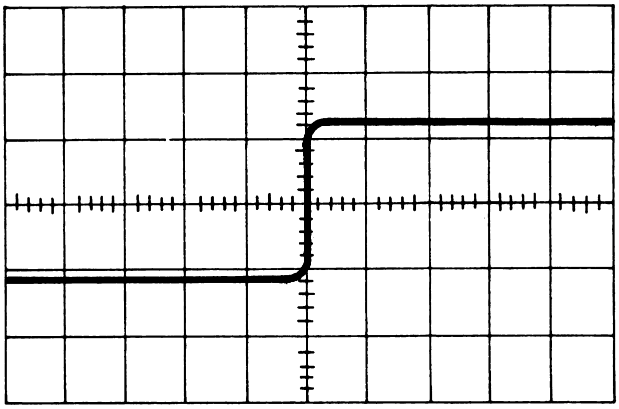
The delayed sweep mode of operation may be used to make accurate time measurements. The difference in time between two pulses, as shown in figure 16-34, is determined by using A INTEN DURING B. The B TIME/DIV should be set to $\frac{1}{100}$ of the A TIME/DIV sweep rate with the B STARTS AFTER DELAY TIME function in use. The delay time multiplier is used to set the intensified portion of the sweep at the peak of the first pulse. The horizontal display is then switched to DELAYED SWEEP (B). The result will be a display as shown in figure 16-35. The DELAY-TIME MULTIPLIER is positioned so that the rising portion of the pulse is positioned on the vertical centerline as shown. The reading of the DELAY-TIME MULTIPLIER is noted. The DELAY-TIME MULTIPLIER is then positioned so that the second pulse is positioned as the first pulse was shown. The DELAY-TIME MULTIPLIER reading is again noted. The difference between the two TIME-DELAY MULTIPLIER readings times the A TIME/DIV setting gives the time difference between pulses. In figure 16-34 and figure 16-35, with the A TIME/DIV setting of 0.5 μsec, the difference is

$$(7.45 - 1.23) \times 0.5$$

$$= 3.11\ \mu\text{sec}$$



AQ. 352
Figure 16-34.–Time difference.



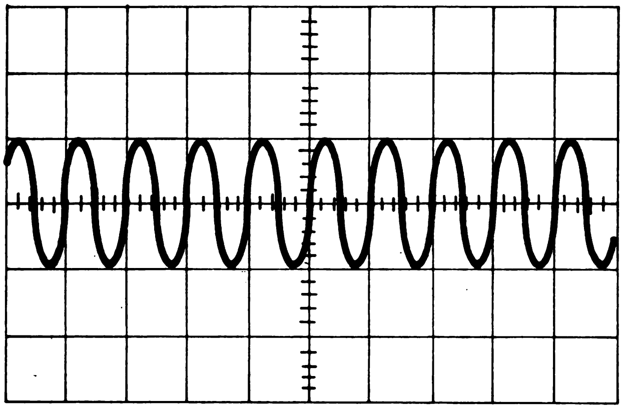
AQ. 353
Figure 16-35.–Magnified pulse time difference.

Delayed Sweep Magnification

When higher apparent magnification than the X10 magnification will produce is desired it may be accomplished by using the A INTEN DURING B and the DELAY-TIME MULTIPLIER. The signal is displayed, as shown in figure 16-36, by using the DELAY-TIME MULTIPLIER to determine when the intensified portion of the sweep starts and using the B TIME/DIV to set the length of the intensified portion of the signal. When the DELAYED SWEEP (B) control is operated, the result will be the display shown in figure 16-37. The apparent magnification of this sweep is found by dividing the A TIME/DIV setting by the B TIME/DIV setting. If the A TIME/DIV is 0.1 msec and the B TIME/DIV setting is 2 μsec, then the apparent magnification is

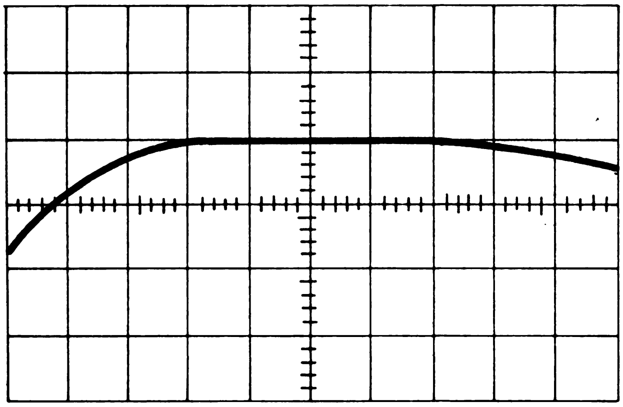
$$\frac{0.1\ \text{msec}}{2\ \mu\text{sec}}$$

$$= 50$$



AQ. 354

Figure 16-36. –Signal before magnification.



AQ. 355

Figure 16-37. –Signal after magnification.

Triggered Delayed Sweep Magnification

The difference between this operation and the delayed sweep magnification is that in this operation the B sweep is triggered after the delay from the signal on the B sweep. This will give a more stable B sweep but the B sweep trigger controls must be positioned properly.

Delayed Trigger Generator

When the A INTEN DURING B function is used and the A sweep is triggered internally, there is available at the B GATE output a triggering signal for use with some external equipment. The trigger available starts at the beginning of the intensified portion of the A sweep and its duration is determined by the B TIME/DIV setting. If the external equipment responds to positive going triggers, it will be triggered at the beginning of the intensified portion and if it responds to negative going signals it will be triggered at the completion of the intensified portion.

Trigger Generator

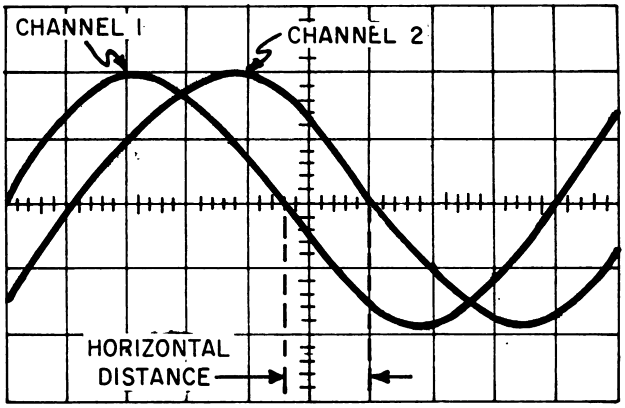
The oscilloscope may be used to trigger external equipment by the A GATE fed to the external signal source. The A trigger LEVEL should be fully clockwise, the A sweep mode to AUTO trigger, and the A TIME/DIV to the desired setting. In this case the external signal source will be triggered by a signal that has a fixed time relationship to the sweep and the signal source output will be displayed as the oscilloscope trace.

Phase Difference Measurements

To measure the phase difference between two signals of the same frequency the signals should be displayed as shown in figure 16-38. The signals are fed into channel 1 and 2 respectively with the reference signal preceding the comparison signal in time. Set the reference signal so that one cycle occupies exactly 9 divisions horizontally. This is accomplished by use of the A variable control. Since one cycle occupies 9 divisions, each division represents 40° per division. The phase difference is the number of divisions times 40°. In figure 16-38, the phase difference is

$$40^{\circ} \times 2 = 80^{\circ}$$

A more accurate measurement may be obtained by using the X10 magnification. In this case the phase difference per division will be $40^{\circ} \div 10$ or 4°.

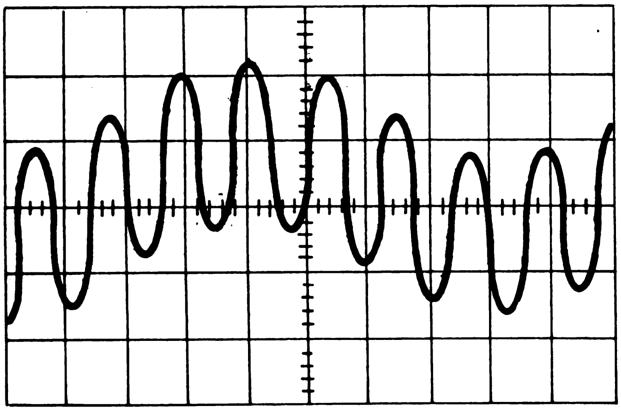


AQ. 356

Figure 16-38. –Phase difference measurements.

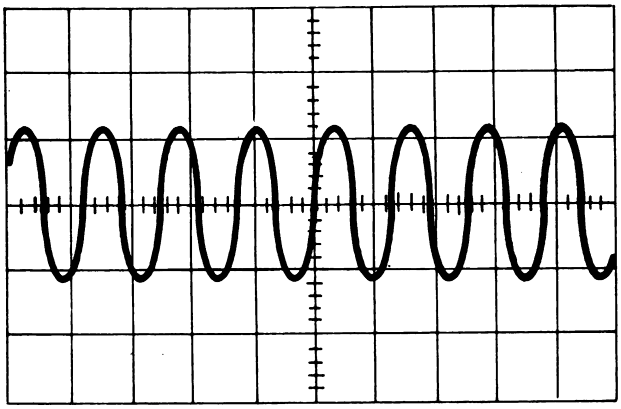
Unwanted Signal Rejection

If a signal displayed contains an unwanted component, as shown in figure 16-39, the unwanted component, in this case a line-frequency signal, may be removed by use of the ADD feature of the oscilloscope. With the signal in figure 16-39 coupled to channel 1, couple a line frequency component to channel 2. Invert channel 2 and use the ADD position. The signal on channel 2 will add to the signal on channel 1 and the result will be as shown in figure 16-40. This is due to the line-frequency components being opposite in polarity and when added they cancel each other.



AQ. 357

Figure 16-39. –Line-frequency component present.



AQ. 358

Figure 16-40. –Line-frequency component canceled.

REPAIR AND CALIBRATION OF TEST EQUIPMENT

The technician is limited to some extent in the corrective maintenance that he is able to perform on test equipments (and still have them function accurately and reliably), principally because he does not have the tools and equipment, and sometimes the spare parts, necessary for this specialized form of maintenance. Therefore the technician should realize the limitations imposed upon the repair of certain test equipments, and in no case should he attempt repairs until the applicable Service Instruction Manual has been thoroughly read. Particular note should be made of possible circuit misalinement or need for recalibration resulting from parts replacement. In the corrective maintenance section of the test equipment instruction manuals, troubleshooting charts are provided for the localization of trouble. When charts are supplied, they should be utilized for the correction of any trouble.

REPAIR

In repairing a piece of equipment a few preliminary tests, along with a logical procedure, often serve to locate the source of trouble without the use of extensive test equipment. In many cases, the reported symptoms along with a few astute observations will indicate the type and probable location of the trouble. Make observations carefully, and keep the symptoms constantly in mind.

The use of the senses of smell, sight, hearing, and touch often localize the source of trouble rapidly. Unusual odors, such as overheated sealing compound, scorched paint, and burning rubber are indications of defective components. If any component emits any unusual odor, the trouble might be in that part or in the associated circuit. Examine for smoking parts or sparking. Notice whether wax impregnated capacitors have lost any wax–this is usually indicative of a defective capacitor. Hum, scratch noises, and other odd sounds should have special meaning for the technician, depending upon the type of test equipment that is faulty.

NONSCHEDULED REPAIR OF TEST EQUIPMENT

Naval Air Rework Facilities (formerly called O & R departments) of naval and Marine Corps air stations provide a source for "call" type rework or repair to meet nonscheduled requirements. Consequently, depot maintenance activities are prepared to manufacture M series source coded items to satisfy replacement needs for operating units. They are also prepared to perform rework of specific items urgently needed to meet immediate demands where other sources are unable to provide support (usually AOCP or ANFE parts not available or not in stock in supply channels). This type of support is classified as "customer service." Operating activities are encouraged to apply to Naval Air Rework Facilities in accordance with local command directives for assistance whenever normal support channels have demonstrated an inability to meet demands. Because the capacity for this type of support, in particular, is severely limited by manpower, material, and funds available, units requesting customer service should exercise thorough self-discipline to insure that normal support channels, including the capability of lower levels of maintenance in repair or manufacturing, have been exhausted prior to applying to the depot maintenance facility for assistance. On the other hand, because the capability of each depot maintenance activity is so varied and extensive, it is better to err on the side of requesting service for which no capability exists than to assume noncapability when the service could be performed.

Other support includes disassembly inspections to determine cause for failure or unsatisfactory performance of an individual item and the resultant disassembly inspection reports (DIR's), preservation, in-service repairs, in-service modifications, and related work. This support is controlled by the Naval Air Systems Command Representatives within funding and man-hour limitations established by the Naval Air Systems Command.

CALIBRATION POLICY

It is the policy of the Naval Air Systems Command that all test and measuring equipment under its cognizance be calibrated periodically and that participation in the established calibration program is mandatory for all Naval Air Systems Command Headquarters managed activities and Navy inspection activities.

Fleet, Reserve, and training units, to which NavAir test equipment is provided for determination of operability and performance of Naval Air material, have the responsibility of insuring that such test equipment is calibrated within the specified periods or exchanged for calibrated equipment. Each Naval Air Systems Command Representative provides for scheduling weapon system test equipment, including ready-for-issue avionics test sets, into Navy calibration laboratories under his cognizance. Also they stock and issue labels, tags, and information pertaining to their use and other technical data on the NavAir calibration program. For further details on the NavAir calibration program, refer to NavAir Instruction 4355 (Series).

Complete recalibration of test equipment should not be attempted by the technician. For the most accurate calibration of test equipment, precision meters, frequency standards, etc., must be used. These precision equipments are not usually found in a shop where maintenance of aircraft equipment is performed. Accurate calibration of the equipment requires the more complete testing and calibrating instruments which are available at a test equipment repair facility

CHAPTER 17

AVIATION SUPPLY

A Chief or First Class Technician, especially if in a supervisory billet, will find himself increasingly involved in the details of supporting the man on the job. One of these detail areas is in the field of aviation supply.

Aviation supply personnel are vital members of the aircraft maintenance team; and the technician, as well as the other aviation maintenance ratings, must work in close harmony with them if successful teamwork is to be achieved. The team must work so that a flow of parts is maintained from the manufacturer to the man on the job–quite possibly a technician doing repair work on the other side of the world. A correct concept of supply's relationship to the entire organization is essential in the supervision of aircraft maintenance functions.

ORGANIZATION

The Aviation Supply Office (ASO) was established in 1941 under the technical control of BuAer and the management control of BuSandA. The function of ASO was the procurement, custody, and issuance of aeronautical spare parts and technical material. This is essentially the function of ASO today under the technical control of the Naval Air Systems Command. Management control is still vested in the Naval Supply Systems Command.

RESPONSIBILITIES OF THE NAVAL SUPPLY SYSTEMS COMMAND

The general functions of the Naval Supply Systems Command within its areas of responsibility include many that are not of primary interest to aviation personnel in that they are not related to aircraft maintenance. Listed below are some of the more important general functions of the Naval Supply Systems Command:

1. Supervises the procurement, receipt, custody, warehousing, and issuance of Navy supplies and materials, exclusive of ammunition, projectiles, mines, explosives, and medical supplies.
2. Supervises and directs the operation of the supply phases of the Navy Supply System and administers the redistribution program of excess personal property within the Department of Defense and the sale of Navy surplus property.
3. Authorizes and supervises the transportation of Navy property.
4. Prepares budget estimates and administers funds for the supply distribution system.
5. Renders an annual report to the Congress of money value of supplies on hand at the various stations at the beginning of each fiscal year, the disposition thereof, purchase and expenditure of supplies for the year, and balance on hand.
6. Coordinates the compilation and arranges for the printing of the Catalog of Navy Material.

Some additional functions of the Naval Supply Systems Command that are of interest to naval aviation maintenance personnel are the general functions of ASO. These include the following:

1. Responsibility for overall determination of requirements, procurement, and distribution of standard aeronautical materials. (Certain materials excepted; e.g., complete aircraft and engines, complete electronic equipment, major photo equipment, nonstandard and experimental aerological equipment, and items of naval weapons ordnance equipment.)
2. Maintenance of a complete file of ASO and Naval Air Systems Command contracts, letters of intent, amendments, extensions, and change orders, and distribution of copies of documents necessary to Navy field activities.
3. Stock control of aeronautical materials at all aviation supply facilities, including control of packing, preservation and distribution of material under ASO cognizance to, from, and between aviation supply facilities and major supply points.
4. Maintenance of complete records of material on order and followup procedure necessary to effect timely deliveries for all material under ASO cognizance.
5. Maintenance of up-to-date records of existing storage facilities at depots, major

supply points, and operation stations for aeronautical materials, and control of influx of materials in aviation supply channels so as not to exceed existing storage facilities.

6. Determination and disposition of obsolete and excess aeronautical material under the Naval Air Systems Command cognizance.

7. Preparation and distribution of the Navy Stock List of the Aviation Supply Office, including interchangeability data.

8. Compilation and distribution of some allowance lists subject to approval by the Naval Air Systems Command.

9. Compilation of lists of spare parts to be salvaged from surveyed aircraft.

10. Followup on delivery, stock recording, reallocating as necessary, and distributing change material promulgated by the Naval Air Systems Command.

11. Establishment and maintenance of a statistical unit which assemblies, compiles, and analyzes usage data.

12. Maintenance of a representative at each aircraft manufacturer's plant who keeps ASO fully informed, as requested, as to all changes which affect spare parts under procurement.

13. Establishment of an inspection service which inspects aviation supply activities within established naval districts.

APPROPRIATIONS

At one time or another, almost everyone has had the frustrating experience of not being able to draw from supply some item that he thought necessary to have immediately; the usual reason given being, "We don't have any money left." It takes only a short time to realize that the Navy does not operate with unlimited funds. This section and the following section, titled "Allotments," are presented to further an understanding of the system whereby funds are made available at the user activity level for operating expenses.

The main money pool of the government is the General Fund of the Treasury. Funds come into the General Fund from such sources as income taxes, excise taxes, import-export taxes, etc. The only way for money to be expended from the General Fund is by congressional action, which has to be approved by the President. A bill passed by Congress which includes the expenditure of funds from the General Fund is called an appropriation.

An estimate of the amount of money required for the operation of the Defense Department during a given fiscal year is prepared by Department of Defense fiscal experts well in advance of the beginning of the fiscal year. The Congress studies the proposed budget in the light of world affairs, the current domestic economy, and such other considerations as they see fit, then acts upon it. They may increase the amount requested, decrease it, or pass it as is. After presidential action is completed, the money is made available to the Department of Defense to be spent during a specified year. This is known as an "annual" or "1-year" appropriation.

Congress and the President may also approve "no-year" appropriations for special projects such as large construction over an unspecified length of time. Another form of appropriation is the "multiple-year" appropriation for projects which will be completed in a predictable length of time. An example of this type of appropriation might be the money appropriated to cover the expenses of the NROTC college programs for the next 4 years.

The appropriation by which the technician is most affected is the current year appropriation. After the appropriation or expenditure authorization is received in the Department of Defense, it is prorated among the services as a percentage of their previously submitted budget estimates. The Navy's share is prorated among the various bureaus and commands in essentially the same manner; that is, as a percentage of their estimated requirements for the coming fiscal year. The money to be spent for naval aviation is made available to the Naval Air Systems Command. Here, part of the money is allocated to ASO for the purchase of aircraft spare parts in quantities which past usage data has indicated will probably be sufficient for the coming year. These spare parts are furnished to the operating activities at no cost, since their usage has been anticipated and the items paid for in advance. The account from which money was spent to buy these items is known as the Appropriation Purchase Account. Material received in the user activities from this account is known as APA material.

Another part of the Naval Air Systems Command funds is made available to the operating activities in the form of allotments.

ALLOTMENTS

Allotments concerning naval aviation are authorizations by the Naval Air Systems

Command to the user activities to spend a certain amount of money during a given length of time for specific purposes. User activities are shore commands, which operate aircraft, and the major air type commanders. Major air type commanders are Commander, Naval Air Force, Atlantic (ComNavAirLant); Commander, Naval Air Force, Pacific (ComNavAirPac); Chief of Naval Air Training (CNATra); and Chief of Naval Air Reserve Training (CNAResTra): Operating funds for squadrons and units are apportioned to them by their type commander as an Operating Target (OPTAR). Routine nonaviation expenses for operating squadrons and units are absorbed by the ship or station to which assigned.

There are three types of allotments–operation and maintenance, operation and line maintenance of aircraft, and aviation fleet maintenance. These three allotments are of particular concern to the technician and are discussed further.

Operation and Maintenance Allotment

Funds in this allotment are made available to commanders of the shore establishment to pay their operating expenses, exclusive of aircraft operating expenses. This money is used to pay civilian labor, buy office supplies, and to pay for all other upkeep and housekeeping supplies. Squadrons aboard the station have no allotment of this type and are dependent on the station for their support. A segment of the station's allotment is allocated to the squadrons for their nonaviation routine expenses. Funds from this source are generally scarce, but it is possible by careful management to make them last through the specified spending period. Shore commanders, in some cases, may elect to provide basic supplies in limited amounts to the tenant activities without providing any funds which the squadron or unit can spend as needed.

Operation and Line Maintenance of Aircraft Allotment

Major air type commanders and shore commands which operate aircraft are furnished this allotment by the Naval Air Systems Command. The OPTAR provided to fleet squadrons and units by their type commanders is usually a monthly segment of these funds. Unused funds revert to the control of the type commander as each new OPTAR is authorized. Type commanders provide OPTAR's to all squadrons and units under their operation control, whether or not the user activity is based ashore. Shore station commanders have no responsibility for providing money for the operation and line maintenance of aircraft of tenant fleet activities.

Funds allotted for the operation and line maintenance of aircraft may be used to buy any type material as long as the material is used for the purpose of the allotment. By far the greatest expenditures against this account are for fuel and oil. Other materials that may be purchased with this allotment include rags, aircraft paints, preservatives, crewmen's flight clothing, or anything else that is consumable due to its use on or about the aircraft.

Aviation Fleet Maintenance Allotment

Air type commands are furnished this allotment by the Naval Air Systems Command, then the Air type command will furnish funds to ships by OPTAR, and fleet support stations are funded by suballotment. These funds are provided to finance the cost of intermediate and organizational levels of maintenance. These costs include the following:

1. Technical repair parts, common hardware, lubricants, cleaning agents, cutting compounds, metals, etc., incorporated into or expended in the performance of aviation maintenance of aircraft, aircraft engines, aeronautical components and subassemblies, and Navy maintenance of the Naval Air Systems Command authorized maintenance support equipment.
2. Fuels and lubricants consumed by aircraft engines in the performance of complete section repair.
3. Preexpended, consumable maintenance material.
4. Replacement of consumable/expendable allowance list items (Material Accountability and Recoverability Codes "B" and "C").

DISTRIBUTION SYSTEM

The aviation supply distribution system consists of reserve stock points, primary stock points, secondary stock points, and satellites. These are discussed briefly in the following paragraphs.

1. RESERVE STOCK POINTS carry reserve and backup stock for the aviation supply system. The range and quantity of stock are determined by the Aviation Supply Office. Reserve stock points provide storage facilities for bulk material.

2. PRIMARY STOCK POINTS carry stock for their own consumption. They may be designated as support activities for secondary stock points, for fleet units, and/or yard and district craft in the area.

3. SECONDARY STOCK POINTS carry stock for their own consumption as well as stock for aircraft and assigned yard and district craft.

4. SATELLITES are aviation activities which are dependent for support on a primary or secondary stock point. Satellites are usually minor activities and normally receive their supply support on a retail issue outlet basis.

As far as the consumers are concerned, they may be assigned to any of the primary, secondary, or satellite stock points for supply support. The same basic principles will affect your supply support. (Hereafter in this training manual, they are referred to as field supply points.)

MATERIAL IDENTIFICATION

As aviation maintenance personnel, we will be working closely with the aviation storekeepers in keeping aircraft in an "up" status. In order to obtain replacement parts as rapidly as possible, we must know how to determine the source of supply of different items. For example, we may waste many hours trying to find out that the item is to be manufactured within our own activity. Also, it is important to know the correct stock number and cognizance symbols used to requisition items from supply.

The cataloging system developed by the Department of Defense is such that it identifies with one name and stock number any item of supply that is carried in any or all government agencies. In the procurement of material it is normally necessary to identify your material requirement in the medium understandable to the supply system.

FEDERAL STOCK NUMBERS

Prior to 1952 each of the services had its own numbering system for idenfityying, cataloging, stocking, and issuing items of military supply. It was not unheard of that one service would be negotiating on the open market for an item that was held in surplus by another service under its own stock number. This confusion resulted in the passage in 1952 of the Defense Cataloging Standardization Act.

The implementation of this Act has resulted in a reduction of item duplication between the services by providing for one Federal Stock Number (FSN) for each item, regardless of the use of the item or the using activity.

Coded Federal Stock Number

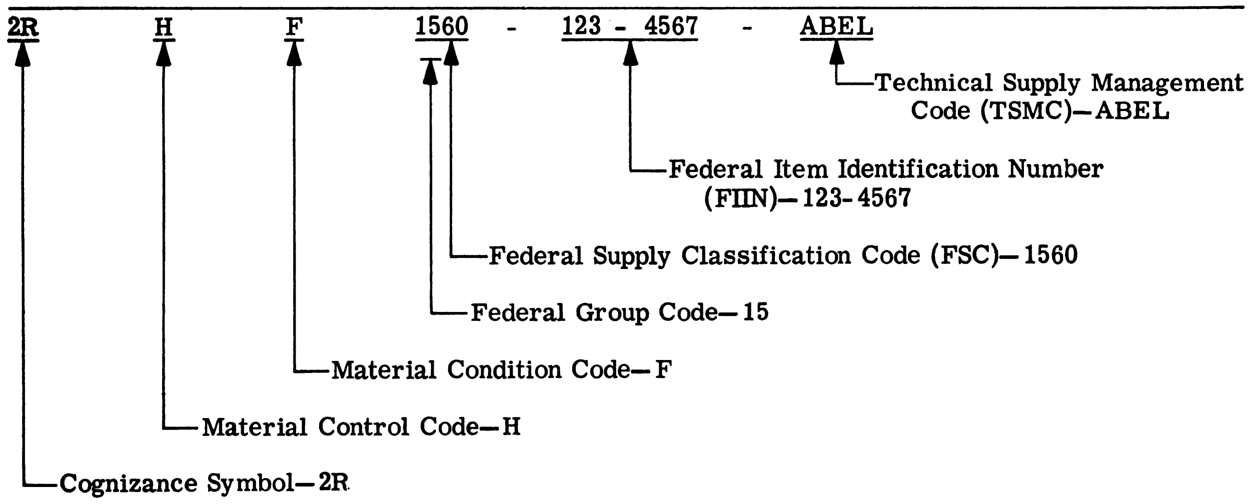
The federal stock number consists of an 11-digit number. The Aviation Supply Office uses federal stock numbers with prefixes composed of one, two, or three symbols, and suffixes composed of four characters which may be all letters or a combination of letters and numbers. When the prefixes and suffixes are used, the federal stock number becomes a coded federal stock number. A coded federal stock number and its breakdown is shown in figure 17-1.

If a 1-symbol prefix is used, it designates the command or office having control or cognizance of a particular item. Listed below are some of the more common cognizance symbols, together with the type material controlled and the name of the cognizant command or office.

SYMBOL	COGNIZANT ACTIVITY	MATERIAL CONTROLLED
2R	Aviation Supply Office	Aeronautical material
2V	Naval Air Systems Command	Major aeronautical equipment
1N	Electronics Supply Office	Electronic assemblies and repair parts
1W	Fuel Supply Office	Fuels, lubes, and gases
1I	Navy Supply Depot, Philadelphia	Forms
0I	Navy Supply Depot, Philadelphia	Publications

Many variations of coded stock numbers will be encountered in field maintenance work. These variations indicate material management responsibilities for the item; flag certain items as recoverable, consumable, high value, etc.; and identify the condition of the material if it is not ready for issue. Some of the more common codes that a technician is likely to encounter include the following:

RH—a recoverable aeronautical component of high value.


2R H F 1560 - 123 - 4567 - ABEL
Technical Supply Management Code (TSMC)—ABEL
Federal Item Identification Number (FIIN)—123-4567
Federal Supply Classification Code (FSC)—1560
Federal Group Code—15
Material Condition Code—F
Material Control Code—H
Cognizance Symbol—2R

AQ. 359

Figure 17-1.–Breakdown of Coded Federal Stock Number.

2RHF—a recoverable aeronautical component of high value that is not ready for issue.

Because the variety of codes is so extensive and the trend to single service management of items has caused so many changes in recent years, a list of codes that might be prefixed or suffixed to a stock number would not be appropriate for this manual. The primary things to keep in mind are that the basic stock number, consisting of three groups of numerals, identifies the item from a technical point of view and that the other codes identify material management characteristics.

With the advent of the single manager concept, many items formally carried in the individual Navy Stock Lists are cataloged in the Federal Supply Catalog for General Supplies. The complete catalog consists of many sections and is arranged by federal supply classification class.

MATERIAL IDENTIFICATION AIDS

There may be times when a part or some technical material is needed and the stock number is unknown. At other times some material may be on hand and its identity is not positively known. A knowledge of the several methods by which material may be identified is very helpful in speeding the completion of a maintenance task. There are many ways in which material may be identified. Certain data may be available which does not identify an item but may lead to positive identification. An aircraft part has a part number. The part number may be looked up in the IPB and identified by nomenclature and often by the stock number. If the stock number is not furnished in the IPB, it may be found by referring to the Cross-Reference Section C0006 of the Navy Stock List of ASO.

Some equipments have attached nameplates which provide such information as the manufacturer's name, make or model number, serial number, size, voltage, phase, etc. Identification data taken from the nameplate of the old part can be very helpful in procuring a replacement.

When only the description of the item is known, the best source for identification is the descriptive sections of the various Navy Stock Lists.

Various publications used in identifying material are described in the following paragraphs.

NAVSUP PUBLICATION 2002, SECTION VIII, PARTS C and D, contains a complete numerical listing of all available naval aeronautic publications distributed by Naval Air Systems Command. This stock list is supplemented by and should be used in conjunction with NavAir 00-500A, Equipment Applicability List, and NavAir 00-500B, Aircraft Application List. These lists are handy references to publications that should assist you in the identification of material.

ILLUSTRATED PARTS BREAKDOWN (IPB) lists are probably the most important tool for the identification of aeronautical material. As a senior Petty Officer, you are undoubtedly familiar with them. However, due to the importance attached to them as a material identification source, they are discussed briefly in the following paragraphs.

IPB's are compiled by the manufacturer for each aircraft model in naval use. IPB's, as discussed here, encompass IPB's for aircraft, IPB's for aircraft engines, and IPB's for individual accessories and equipments.

Although slight variations in format exist among the various IPB's, each normally includes the following major sections:

I. TABLE OF CONTENTS—This section shows the breakdown of the catalog into sections and furnishes a cross-reference between the various assemblies and figures where they are illustrated. The section also cross-references assemblies and pages where they are broken down into subassemblies and parts.

II. INTRODUCTION—This section includes general information and instructions for using the publication. Because variations between IPB's do exist, this section should be referred to prior to using an IPB with which you are not thoroughly familiar.

III. GROUP ASSEMBLY PARTS LIST—This section is the main text of the publication. It consists of a series of illustrations and parts lists in which all parts of the aircraft/engine/equipment are shown in assembly breakdown order. The illustrations and parts lists are keyed to each other by means of figure and index numbers. Each assembly included in the parts lists is followed immediately by its component parts properly indented to show their relationship to the assembly. The group assembly parts list is subdivided into groups such as wing group, tail group, and fuselage.

IV. NUMERICAL INDEX—This section lists all parts in alphanumerical order, and each part is cross-referenced to the figure and index number where it is illustrated. This list also shows the official source code of each part listed in the applicable IPB.

Source codes are codes which indicate to a consumer a source for a part required in the maintenance of repair of an aeronautical article. They are provided in six series—P, M, A, N, X, and U.

The REFERENCE DESIGNATOR INDEX, normally the last section of the IPB, is a listing of reference designators (C104, R603, K202, etc.) used on the electrical and electronic wiring diagrams. The reference designator index will aid in the location of parts where only the reference designation number is known.

Source code P series parts are parts of supply system stock which are purchased.

Source code M series applies to parts which are not purchased but are capable of being manufactured at Navy fleet or overhaul activities (MF, MO, or MOA).

Source code A series applies to assemblies which are not purchased.

Source code N applies to nonstock items which are purchased on demand.

Source code X applies to main structural members or similar parts, which, if required, would suggest extensive repair. The need for a part or parts coded X normally results in a recommendation for complete overhaul or retirement of the equipment from service.

Source code X1 applies to items for which purchase of the next larger assembly, source coded in the P series, is justified.

Source code X2 is applied to items which are not purchased for stock, but may be acquired for use through salvage or one-time purchase. Activities requiring such items should attempt to obtain them from salvage; if not obtainable from salvage or readily manufactured, such items may then be requisitioned through normal supply channels with supporting justification. Repeated requisitions could justify a change to the P series code.

Source code U applies to parts which are not of supply or maintenance significance, such as installation drawings, diagrams, instruction sheets, etc.

Within each of the source code series listed above there are one or more subcodes identified by a letter or number appended to the basic code letter. These subcodes provide detailed information concerning the procurement or manufacture of various parts within the scope of the particular code series. The introduction section of the applicable IPB provides a ready reference for each of the codes and subcodes as required.

Aeronautical Allowance Lists

Aeronautical allowance lists as used in this manual include NavAir Allowance Lists, NavAir Initial Outfitting Lists, and NavAir Tables of Basic Allowance.

Aeronautical allowance lists are lists of equipment and material, known or estimated to be required, to place and maintain aeronautical activities in a material readiness condition.

These lists contain substantially all items used with sufficient frequency to justify their issuance to all activities maintaining aircraft or equipment for which the lists are designed. They also contain information concerning stock number, nomenclature, interchangeability, and supersedures. These publications are further defined in subsequent paragraphs. Keep in mind that allowance lists normally contain support equipment allowed to maintenance personnel consistent with their assigned level of maintenance. Initial outfitting lists contain material of a spare parts nature required for maintenance of aircraft/equipments. Materials listed in the initial outfitting lists normally are held in supply stocks and under most conditions are not authorized shop spares.

Allowance lists indicate the range and quantities of support equipment considered necessary for maintenance support of assigned and/or supported aircraft. Generally, these items are in-use items required for daily or continual use, such as handtools and avionics test equipment.

Initial outfitting lists (IOL's) are publications which indicate the range and quantities of maintenance spare parts considered necessary to support various aeronautical articles. This material is provided to vessels or activities and is firm only at the time of initial outfitting. Increases and decreases in both range and/or quantities of material are based upon the experience (demand history) of each activity concerned. Each series list is designed to support an aircraft, electronic equipment, or some other aeronautical article. The allowances of material are established for various articles for a 90-day period. All items capable of replacement by a maintenance activity are not listed, but rather, only those that are expected to be used at least once in 9 months.

Publications listing equipment and material required for performance of specific functions are known as Tables of Basic Allowance. They contain both shop equipment and common supporting spare parts. They cover allowances of tools and equipment required for use by such activities as Fleet Marine Force squadrons and guided missile activities.

Initial Outfitting Lists and Allowance Lists are identified by the publication number NavAir 00-35Q, series while Tables of Basic Allowance are identified by the publication number NavAir 00-35T series. Those allowance lists of primary interest are listed in the following paragraphs:

Section "A" Initial Outfitting List (NavAir 00-35QA-1)-
  Lists standard aeronautical and Navy stock account material common to the designated aircraft classes.

Section "B" Initial Outfitting List (NavAir 00-35QB)-
  Series lists peculiar maintenance parts (airframe, engine, accessories) required for support of specific aircraft models. (Includes lists for certain target aircraft and guided missiles.)

Section "BR" Initial Outfitting List (NavAir 00-35QBR)-
  Series lists peculiar maintenance parts (airframe, engine, accessories, electronics) required for support of concerned target aircraft model, drone helicopter, or guided missile. (Prepared in lieu of separate Section "B" for airframe, engine, accessories, and Section "R" lists for electronic parts due to limited installation of electronic equipment.)

Section "G" Allowance List (NavAir 00-35 QG)-
  Series lists general maintenance support equipment and handtools required for intermediate and organizational levels of maintenance support of aircraft.

Section "R" Initial Outfitting List (NavAir 00-35 QR-4)-
  Lists general aeronautical electronics material common to and required for maintenance of avionics equipment and systems.

Section "R" Allowance List (NavAir 00-35QR-5)-
  Lists avionics support equipments required for maintenance of installed avionics equipment and systems. A confidential supplement to NavAir 00-35QR-5 is issued as a separate publication.

Section "R" Initial Outfitting List (NavAir 00-35QR-5A)-
  Lists peculiar parts required for maintenance of electronic test equipments authorized in NavAir 00-35QR-5.

Section "R" Initial Outfitting List (NavAir 00-35QR-6)-
  Lists aeronautical electronic accessories common to designated aircraft classes.

Section "R" Initial Outfitting List (NavAir 00-35 QR-7)-
  Lists electron tubes required in the maintenance of aeronautical equipment utilizing such tubes.

Section "R" Initial Outfitting List (NavAir 00-35QR-30)-

Series lists peculiar parts, spare components, assemblies, and subassemblies required for maintenance of appropriate aeronautical electronic equipments.

Section "T" Allowance List (NavAir 00-35QT)-
Series lists special maintenance support equipment required for intermediate and organizational levels of maintenance of airframes, powerplants, accessories, avionics equipment, and/or aircraft model to which the list applies.

Section "X" Initial Outfitting Allowance List (NavAir 00-35QX-30)
Series lists peculiar parts, spare components, assemblies, and subassemblies required for maintenance of the armament, fire control, instrument, or electrical system to which the list applies.

Section "Z" Initial Outfitting List (NavAir 00-35QZ)-
Series lists peculiar parts for electric power-plants, special and general aircraft, and guided missile support equipment.

Tables of Basic Allowances (NavAir 00-35T)-
Series (T-37-1, T-37-2, T-37A, T-38, T-39, T-40, and T-41) lists equipment and material required by activities to which the list applies for performance of assigned mission. Lists presently in effect relate to the following activities:

T-37-1, T-37-2–Fleet Marine Force Aviation Units.
T-37A–Fleet Marine Force Aviation Units (Supply Officers' material and equipment).
T-38–Target Pilotless Aircraft Activities; Drone Aircraft Catapult Control Craft; Navy Tactical Control Squadrons.
T-39–Regulus Guided Missile Activities.
T-40–Air-Launched Guided Missile Activities.
T-41–DASH Weapons System Operational and Maintenance Activities

Stock Catalogs

Stock catalogs provide information necessary to procure items for operation and maintenance of activities afloat and ashore. The stock catalogs commonly used by aviation maintenance personnel are the Federal Supply Catalog for General Supplies and the Navy Stock List of ASO for aeronautical material.

The Navy Stock List of ASO is divided into four parts, each consisting of several volumes. Many of these stock list sections are designed for supply management purposes and have very little significance to maintenance personnel. The sections normally utilized by maintenance personnel include the following:

1. Sections C0006 and C0009 are cross-reference sections. The section C0006 is used to cross-reference a manufacturer's part number to a federal stock number. The section C0009 is used to cross-reference a federal stock number to a manufacturer's part number. These are multiple volume sections and are not normally available in individual shops, but may be available in a centralized area for use by several shops. These sections are published annually with cumulative supplements being issued monthly.
2. Parts list sections provide supply data to supplement information contained in the Illustrated Parts Breakdown. These sections contain valuable information relative to application and interchangeability. Parts list sections are set up by TSMC. Each section contains an application checkoff list, a listing of repairable assemblies, and a listing of supporting spare parts.
3. Descriptive sections are used when only the item nomenclature and physical characteristics are known. Illustrations are provided to aid in the identification of items that cannot be defined by words. The descriptive sections are established by federal supply classification class.

MATERIAL REQUISITIONING

Maintenance personnel are apt to encounter a variety of local requisitioning channels; all designed to present a demand for an item to the supporting supply department. Assigned levels of maintenance, geographical location of shops relative to supply facilities, and mission of activities requiring support all influence the local requisitioning channels. Local instructions normally promulgate detailed procedures for submitting your demand to the appropriate supply point.

SUPPLY ACTIVITY

The mission of the supply activity is to support the operational and maintenance efforts of the activity/ship. Stocks of aviation oriented material carried are tailored and replenished to to this end. Positioning, replenishment, and control of stocks of material in maintenance area are carried out as a result of joint decisions by the Supply and Maintenance Officers concerned. They determine the range, depth, and related procedures. The Navy Maintenance and Material Management System (Aviation) requires that the cost of material used in maintenance be determined and accumulated in such manner and detail that weapons system costing can be measured. Usage is finely defined as to stock number, within component, within equipment/weapon/aircraft, in a particular squadron, located in a specific operational area, at a definite point in time. These data are used as an inventory management tool to determine geographic and strategic distribution of stocks of material. In addition, the data will be invaluable in establishing the material portions of work standards in maintenance.

Supply Support Center

Maintenance organizations have one single point of contact with the supporting supply activity. This single supply contact point is the Supply Support Center (SSC) which responds to all material requirements of the maintenance organizations. The SSC is an internal organization of the local supply activity. It is made up three sections–the Supply Response Section, (SRS) the Component Control Section, (CCS) and the Supply Screening Section (SSS).

Supply support is available consistent with the operating hours of the maintenance activities supported. If maintenance is being performed 24 hours a day, then supply support is available 24 hours a day.

The supply support center maintains rotatable pool material which consists of repairable ready-for-issue items reserved primarily to satisfy the requirements of organizational level maintenance. Items maintained in the pool are capable of being repaired by the local intermediate maintenance activity, have application relationship to weapon systems supported by local intermediate maintenance activities, and have an average organizational maintenance level removal rate of at least one per month. Defective components are turned in to intermediate level maintenance for repair. The defective components repaired to an RFI condition are then returned to the rotatable pool to replace the components previously issued.

Low value, fast moving consumable items are preexpended from supply. Such materials are located in the maintenance area. The establishment, maintenance, and replenishment of preexpended bins are the responsibility of the supply organization.

SUPPLY RESPONSE SECTION–The Supply Response Section (SRS) is responsible for preparing all necessary requisitions (DD Form 1348) and related documents required to obtain material for local maintenance use in direct support of weapon system maintenance. The maintenance organization verbally notifies the supply organization of the need for such material. When material is available locally, the time frame for processing and delivery is as follows:

Priority	Process/Delivery Time
1-3	1 hour
4-8	2 hours
9-20	24 hours

Otherwise, the time frames as noted in table 17-1 will apply.

The SRS is responsible for receipt, storage, and issuance of all ready-for-issue pool components. It is responsible for physical delivery of RFI material to maintenance organizations, and the pickup of defective components from the organizational maintenance activity and subsequent delivery to the intermediate maintenance activity. Actual maintenance personnel are not involved in the physical movement of material between organizations.

This section also performs technical research in regard to completion of requisition documents as well as determining the status of outstanding requisitions and relaying this status to the customer upon request.

COMPONENT CONTROL SECTION.–The Component Control Section (CCS) accounts for all components being processed in the intermediate maintenance activities. This section also records on the status of all rotatable pool components.

SUPPLY SCREENING SECTION.–The Supply Screening Section (SSS) is responsible for initiating disposition action on components that cannot be repaired by the local intermediate maintenance activity. Using listings and directives from inventory managers, screening personnel determine disposition of components in question, including prospective consignee and packaging, and preservation requirement prior to movement of material.

Table 17-1.—Processing time frames.

Issue Group	Issue Priority Designator Range	Supply Source Processing	CONUS On Station Time	Overseas On Station Time
1	1-3	24-day workweek 24-hour day 7-day workweek	120 hours	168 hours
2	4-8	72 hours 24-hour day 7-day workweek	8 days	15 days
3	9-15	10 days 8-hour day 5-day workweek	20 days	45 days
4	16-20	12 days 8-hour day 5-day workweek	30 days	60 days

MATERIAL CONTROL OFFICER

The Material Control Officer in a maintenance activity is an assistant to the Maintenance/Material Control Officer, as such provides support and services to the production divisions. Material Control exists for the primary purpose of insuring that maintenance requirements for parts and materials are made known to the supply organization in a timely manner in order to prevent work stoppages and grounding aircraft. Material Control insures that parts and materials made available to maintenance are systematically utilized and not allowed to accumulate or to become depleted. It serves as the single point of contact within the maintenance organization for the conduct of business with the supply organization.

Material Control provides material support to their cognizant organization by accomplishing the following general functions:

1. Pass all requirements for material required for direct support of weapon system maintenance to the SSC. A material control register is maintained for these items.
2. Prepare documents for materials required for indirect support of weapon system maintenance. Examples of materials for which documents are to be prepared are aviation fuels and lube oils, rags, and flight jackets. A separate requisition record log is maintained for these items.
3. Maintain liaison with the supporting SSC on maintenance material matters to insure that material needs of the organization are satisfied.
4. Establish delivery points for all material and insure that material received is expeditiously routed to the applicable work center.
5. Furnish technical advice and information to the supply activity on the identity and quantity of supplies, spare parts, and materials required for maintenance actions.
6. Establish procedures to insure the periodic inventory of tools and the adequate accountability of material and equipment on custody to the cognizant organization.
7. Initiate surveys in the event of loss, damage, or destruction of accountable material.
8. Keep maintenance control advised of the overall supply situation as it affects the activity.
9. Perform cost and allotment record accounting, charting, and budgeting of cost applicable to the cognizant organization.
10. Monitor the operation of toolrooms and maintain support equipment allowance lists.
11. Maintain inventory control of authorized allowances of material.

The Material Control is responsible for the coordination of material ordering, receipt, and delivery. This is done in such a manner as to insure that the correct material is ordered and that it reaches the work center within the specified time frame.

The foregoing functions of the material control division apply to both organizational and intermediate level activities. Some of the functions which are applicable to one level only are listed in the following paragraphs.

Intermediate Level

An Administrative Screening Unit has been established in Material Control of intermediate maintenance activities. This screening unit does the following:

1. Positively identifies material and determines if it is within the repair capability of the Intermediate Maintenance Activity (IMA).
2. Insures that all required documentation is affixed to the component (i.e., logs, records, MAF, etc.).
3. Notifies maintenance control of the receipt of defective components for scheduling into the IMA.
4. Transfers the defective components to the appropriate work center when directed by maintenance control.

All components received in the IMA material control receive screening to determine if the item is within the check, test, or repair capability of the IMA. As a result of this screening, components requiring maintenance within the IMA capability are reported to maintenance control as ready for induction. Items beyond IMA capabilities are returned to the Supply Support Center with appropriate recommendations for disposition. When work on components in the IMA has been completed, the components, together with required records, are returned to Material Control for appropriate routing.

Organizational Level

In addition to the general functions, Material Control in organizational level activities is responsible for the following:

1. Verification of NORS (Not Operationally Ready Supply) requisitions and maintain current NORS status records.
2. Inventory of aircraft upon receipt and transfer and maintenance of inventory records.

When removed components are generated as a result of the maintenance effort, Material Control insures that the SSC is notified to make a pickup. These components must be accompanied by record cards and logs, when applicable, plus the number two, three, and four copy of the MAF.

Material Control Register

The Material Control Register is used by intermediate and organizational level activities to record all materials requested from the supply support center in direct support of weapon system maintenance. Space is provided to record essential information considered necessary to monitor OPTAR funds. This information includes part number, priority, quantity, price, date, and time ordered, and date and time received. Maintenance control uses the time ordered and time received to help determine NORS time used in fulfulling readiness reporting requirements.

When a defective repairable item is turned in, the following forms are required: copies two, three, and four of the multicopy MAF and the Accessory and Component Service Record (NavWeps Form 13090/29), when applicable. The supply department sues copy two of the MAF for bookkeeping purposes. Copies three and four of the MAF accompany the item to the IMA. When repair is completed by the IMA, copy four of the MAF is attached to the RFI item and the item is returned to the supply system.

If material being turned in is no longer required and is RFI, a Single Line Item Release/Receipt Document (DDD 1348-1) is submitted with the item. RFI means ready for issue in all respects–preservation still intact and item in original or reusable container with seals unbroken.

MILSTRIP

The Military Standard Requisitioning and Issue Procedure (MILSTRIP) and Uniform Material Issue Priority System were developed by the Department of Defense to provide a common supply language and more effective supply system operations within the military establishment. This system standardizes forms, formats, codes, procedures, and the priority system.

MILSTRIP employs two forms for the requisitioning and issuing of material. The Single Line Item Requisition Document (Form DD 1348) is the basic request document submitted to the applicable supply echelon for material requirements. The issue document is the Single Line Item Release/Receipt Document (Form DD 1348-1). Form DD 1348-1 is also used to return RFI material to the supply system. These forms will be prepared by the Supply Response Section of supply for all material requested in direct support of weapon system maintenance and by the Material Control for material requested in indirect support of weapon system maintenance.

Uniform Material Movement and Issue Priority System (UMMIPS)

In this system, the priority designator is determined by a combination of factors which relate the military importance of the requisitioner (force/activity designator) and the urgency of need or end use (indicated by an urgency-of-need designator). The force/activity designator (a roman numeral I-V) is assigned by the Joint Chiefs of Staff (JCS), Chief of Naval Operations (CNO), and Navy commanders. The urgency-of-need designator (an alphabetical letter) is determined by the requisitioning activity, with certain exceptions. These two factors will enable the requisitioning activity to determine the UMMIPS priority designator (arabic numeral).

The twenty priority designators provided in UMMIPS have been placed into four priority groups. Each priority group qualifies for different processing time standards as prescribed in table 17-1. These priority groups are compatible with the transportation priorities prescribed in the Military Standard Transportation and Movement Procedures (MILSTAMP).

1. Force/activity designators.
   a. A force/activity is:
      (1) A unit, organization, or installation performing a function or mission.
      (2) A body of troops, ships, or aircraft, or a combination thereof.
      (3) A function, mission, project, or program, including those under military assistance (grant aid and/or sales).

2. Selection and assignment of issue priority designators for requisition and issue transactions.
   a. All requests for material normally stocked in a supply system will be assigned an issue priority designator. The issue priority designator normally expresses the relationship between the force/activity designator and the urgency-of-need designator. However, there are certain exceptions and unusual circumstances under which a requisitioning activity is authorized to assign a specific numerical priority designator that represents a uniform need for an item regardless of the force/activity designator assigned. These exceptions are as follows:
      (1) A priority designator of 03 will be used by all activities regardless of force/activity designator in requisitioning high value items required for immediate use; i.e., where urgency-of-need designators A or B are indicated.
      (2) A priority designator of 03 will be used by all activities, regardless of force/activity designator, for medical or disaster supplies or equipment required immediately for prolonging life in case of critical injury, fatal disease, or natural emergency.
      (3) A priority designator of 06 will be used by all activities, regardless of force/activity designator for the replenishment of high value items.
      (4) A priority designator of 06 will be used by all activities regardless of force/activity designator, for individual and organizational clothing required to provide a minimum of essential clothing in the event active duty military personnel are without the clothing required.
   b. Except for conditions referenced above, the requisitioner will:
      (1) Select the applicable urgency-of-need designator for each requisition or order.
      (2) Ascertain the appropriate issue priority designator for the force/activity designator assigned the requisitioning activity and the applicable urgency-of-need code, and enter this number on the material requirement document (NAVSTRIP requisition).
   c. Supply activities, when requisitioning a specific requirement for a supported unit with a different force/activity designator than the supplying activity, will use the priority designator appropriate to the requiring activity.

3. Every activity is assigned 1 of 5 force/activity designations according to their military importance. (See table 17-2). These designators are as follows:

I - COMBAT—The highest order of military importance. This designator is not normally used in peacetime unless approved by the President or the Joint Chiefs of Staff.

II - POSITIONED—United States combat, combat ready, and direct combat support forces deployed outside CONUS in specific theaters or areas designated by the Joint Chiefs of Staff and those CONUS forces being maintained in a state of combat readiness for immediate (within 24 hours) deployment or employment.

Table 17-2.–Priority number chart.

Designator	A Unable to perform	B Impairs capability	C Other than routine	D Routine
I Combat	1	4	11	16
II Positioned	2	5	12	17
III Ready	3	6	13	18
IV Reserve and support	7	9	14	19
V Others	8	10	15	20

III - READY–All other United States combat ready and direct combat support forces outside CONUS not included under designator II.

IV - RESERVE AND SUPPORT–U. S. active and selected reserve forces planned for employment in support of approved joint war plans. This category includes training units and units in training for scheduled deployment.

V - OTHERS–All units not otherwise assigned, including administrative/staff type units.

4. The urgency of need for an aircraft spare part or aeronautical material may be determined in accordance with the following designators (A, B, C, and D):

A - Emergency requirements for primary weapons, equipment, and material for immediate use without which the unit concerned is unable to perform assigned operational missions (NORS), or such condition of readiness is imminent. (See notes 1 and 2.)

Material required for immediate installation on or repair of primary weapons and equipment, without which the unit concerned is unable to perform assigned operational missions (NORS), or such condition of readiness is imminent. (See notes 1 and 2.)

Items required for immediate end use in direct support of equipment essential to the operation of aircraft and equipment (e.g., ground support, firefighting, etc.), or such condition of readiness is imminent. (See notes 1 and 2.)

B - Item(s) required for immediate end use, the lack of which is impairing the operational capability of the aircraft or organizational unit concerned. The aircraft or organizational unit concerned can operate only temporarily as an effective unit; assigned operational missions can be accomplished, but with decreased effectiveness and efficiency.

Item(s) required for immediate end use to effect repairs to aircraft and aircraft support equipment, without which the operational capability of the aircraft is impaired or effectiveness in accomplishing assigned missions is reduced.

Item(s) required to effect emergency repair or replacement of intermediate maintenance activity equipment essential to providing services for aircraft and aircraft equipment.

C - Items required for immediate end use to repair or replace administrative support equipment and equipment or systems not essential to operational missions of aircraft or organizational units.

Items essential to initial outfitting or to completion of allowance/load lists on a more urgent basis than routine stock replenishment.

Material required to preclude a work stoppage or prevent delay in scheduled maintenance of weapons systems or major equipment.

D - Items required for routine stock replenishment.

Items required for initial outfitting and filling of allowances.

Items required for scheduling maintenance, repair, or manufacture of supply system stocks.

NOTE 1: Requirements of this nature are of such a consequence as to require a report to higher authority of a degradation of the requisitioning units capability.

NOTE 2: An imminent condition of degraded readiness exists when material is required to prevent an Anticipated Not Operationally Ready Supply (ANORS) condition. An ANORS condition will exist when it is known that items of material or equipment, not available in the unit, are required within the following time frames:

a. Five (5) days for nondeployed units.
b. Seven (7) days for deployment units.
c. Fifteen (15) days for Vietnam requirements.

PARTS KITS

Parts kits contain supporting items and material for the maintenance, repair, and rework of selected aeronautical repairable type items and will be procured, stocked, requisitioned, accounted for, and used on a kit basis as one line item.

A parts kit consists of a group of maintenance or overhaul parts that are bought, packaged, and stocklisted as a single item regardless of classification that may be included therein. Normally, these parts have either a very low unit cost or have a high replacement rate in overhaul or repair of the next higher assembly. Depending on the complexity of the end item, there can be one or more kits needed for its repair. Parts kits are designed to serve three separate requirements as described in the following paragraphs.

C KIT (CURE-DATED OR SOFT GOODS). This kit provides cure-dated items such as diaphragms, packing, and O-rings. The C kit may also contain soft goods not subjected to age control such as gaskets and seals, plus metallic items such as screws, nuts, and washers required to be removed when cure-dated or soft goods type materials are replaced. Any metallic item placed in the C kit is not duplicated in the D kit. When mixed categories or cure-dated parts are packaged in a single container, the control or cure-date of the package must be that of the oldest cure-dated part contained therein. If cure-dated kits become overaged due to the expiration of the storage limitations, the kit must be administratively disposed of as excess material.

D KIT (OVERHAUL). This kit provides hard good spare parts required for overhaul of equipment by depot level maintenance. This kit does not contain cure-dated parts.

F KIT (FIELD). This kit provides those items that are required to be replaced at intermediate and organizational maintenance levels. These parts are normally items not requiring special tools or equipment. This kit does not contain cure-dated parts.

Part numbers for applicable parts kits for intermediate and organizational levels of maintenance are listed in the Illustrated Parts Breakdown and the Maintenance Instructions Manual. Components of kits are additionally identified in the Illustrated Parts Breakdown by a footnote and a symbol appearing to the right in the part number column and indicating which items are furnished in the kit. The Maintenance Instructions Manual utilizes a symbol keyed to the illustration to indicate parts furnished in the kit.

Presence of a new part in an applicable parts kit eliminates the necessity of cleaning, inspection, or rework of the equivalent part removed from the assembly being repaired. Removed parts in this category must be administratively condemned. Removed parts not supplied in applicable kits must be handled in accordance with instructions contained in the Maintenance Instructions Manuals.

Detailed instructions on parts kits are contained in BuWeps Instruction 4423.2.

PREEXPENDED BINS

A preexpended bin is one which contains low cost, high usage items which have already been charged to final expenditure. Many items of small dollar value are used repetitively in the aircraft maintenance program. The accepted practice is to stock these repetitively used items in the immediate maintenance area in a semi-controlled preexpended bin. Preexpended bins are normally established by the supply department in consort with the maintenance activity and are labeled, stocked, and replenished by the supply department. The normal responsibilities of maintenance personnel in this are:

1. Recommending items to be stocked.
2. Supervising the use of the bins to prevent waste, pilferage, and deterioration of the contents to a scrap heap.
3. Insuring that preexpended bins are separate and distinct from the normal "salvage" boxes located in most shops.

Preexpended bins provide repetitively used items to maintenance personnel with the minimum of effort. The material is immediately available to all shop personnel. The bins also provide the supply department with a constant and realistic demand history.

Nonstandard and/or Navy manufactured items may at times be required. These are normally obtained through the normal supply channels as outlined in local directives.

Manufactured items are those items which are source coded in the M series in applicable illustrated parts breakdown lists. Request documents submitted for manufactured items should contain additional reference data such as, part number, drawing number, and publication reference, or any other information which would be advantageous in the acquisition of the material.

Nonstandard material (material requiring open purchase) may not be procured when standard stock items are available except when the nonstandard material is considered to be indispensable. When the procurement of nonstandard material is considered essential, the originating request document must contain the following information:

1. A certification that no standard stock material is suitable.
2. A justification for the procurement of the nonstandard material.

ROTATABLE POOLS

Rotatable pools consist of a range of selected components maintained by a specific maintenance activity, on custody from the supporting supply department. The items generally carried in the pool are those required to sustain operations where immediate availability is essential. Aircraft wheels, tires, avionics assemblies, propellers, and carburetors are examples of items that might be included in the pools. The range and quantity of items to be carried in the pool are subject to the recommendations of the maintenance activities. The supply department establishes the rotatable pool stock and prescribes detailed procedures for operation and control of the pool.

ACCOUNTING FOR MATERIAL IN USE

Accounting for material does not cease when it is withdrawn from the supply department. It is at this point that the accounting responsibility passes to the applicable maintenance personnel.

AIRCRAFT PARTS

Normally, the accounting for aircraft parts drawn to replace similar defective parts is satisfied when the part is installed on the aircraft. No further custodial records are required. The accounting for materials drawn for general maintenance is satisfied when the material is consumed in the authorized maintenance work. In these cases it is actually the removed defective material that required additional action to insure its accountability from the time it is removed until it is returned to the supply department.

The degree of accountability required for aeronautical material may be ascertained by the material accountability recoverability codes (MARC). Material accountability recoverability codes are a part of the source, maintenance, and recoverability codes which are assigned provisioned items as required by current ASO and BuWeps/NavAir directives. The MARC's appear in the descriptive sections and parts lists sections of the ASO Navy Stock List, NavAir Allowance Lists, and may appear in such other publications as directed by NavAirSysCom. These codes aid personnel to determine the proper method of:

1. Requisitioning material.
2. Accounting for material while in use.
3. Turn-in or disposition of material.
4. Repair or overhaul of material.

The following list defines the various material accountability codes.

B - Exchange Consumables. Code B is applied to items which are consumable or expendable but normally require item-for-item exchange for replacement. Such items may contain precious metals, may be highly pilferable, or may be high cost items.

C - Consumables. Code C is applied to all other consumable or expendable items which do not require item-for-item exchange for replacement.

D - Equipage, Support Type. Code D is applied to end items of support equipment which are economical and practical to repair on a scheduled basis through a major rework activity. Code D items are maintained on a custodial basis and normally require item-for-item exchange for replacement.

E - Equipage, Locally Repairable, Support Type. Code E is applied to end items of support equipment which are to be repaired locally by the using or fleet support activity within their assigned maintenance responsibility. Code E items are maintained on a custody basis and normally require item-for-item exchange for replacement.

R - Equipage. Code R is applied to repairable (except end items of support equipment) items which are economical and practical to repair on a programed basis through a major rework activity. Code R items are maintained on a custody basis in some cases, depending upon the use of the item. These items normally require item-for-item exchange for replacement.

L - Equipage, Locally Repairable. Code L is applied to repairable (except end items of support equipment) items which are to be repaired locally by the using or fleet support activity within their assigned maintenance responsibility. Code L items are maintained on a custody basis in some cases, depending on the use of the item. They will normally require item-for-item exchange for replacement.

Some allowance lists may still be in use which utilize a different accountability code system than MARC. The following equivalents may apply, pending issuance of new publications using the latest material accountability recoverability codes:

MARC	INTERIM	OLD
D	A	A
D	O	A
D	E	AX
R	R	X
B	D	NONE
C	C	C
E	NONE	NONE
L	NONE	NONE

As is apparent upon reviewing the material accountability recoverability codes, the disposition of defective material is largely dependent upon its potential repairability. Codes D, E, R, and L signify that the tiem is repairable and is required to be returned to the supply system even though it is not RFI. The need for the expeditious handling of prospective repairable material cannot be overemphasized. The repair program is the prime source of supply for many critical high value items. Code C items are normally consumed or are not of a repairable nature and do not require turn-in if non-RFI.

An aeronautical material screening unit is established by all activities assigned the responsibility to perform intermediate level maintenance. The basic responsibility of the screening unit is to screen all defective aeronautical matieral generated on the station by tenant squadrons and station operating units prior to further processing of the material by the supply system or higher echelons of maintenance. The screening unit determines if such material is within the repair responsibility of local intermediate maintenance activities and, if so, intiates action to effect its local repair.

Normally, the following sequence of events should be followed in the repair of aeronautical material:

1. The using activity should repair the defective item without removal from the aircraft.
2. The using activity should remove the defective item from the aircraft, check, test, and repair it within their assigned responsibilities and replace it on the aircraft.
3. In the event the item requires repair and the time involved is excessive from the operational or readiness point of view, the using activity may draw a replacement item from supply. The defective item should be forwarded to the supporting intermediate maintenance activity's screening unit.
4. This screening unit determines if the item is within the repair responsibility of the intermediate maintenance activity, and, if so, the item is repaired and forwarded to supply as RFI. If not, the item is forwarded to supply as prospective repairable material.

AIRCRAFT MAINTENANCE SUPPORT EQUIPMENT

Developing and supervising proper procedures to insure the maintenance and accountability of aircraft maintenance support equipment (AMSE) is normally a prime administrative function of the senior technician. Unlike most aircraft parts, AMSE requires the maintenance of custodial records and periodic physical inventories throughout its in-use life.

Aircraft maintenance support equipment as discussed in this chapter applies to all accountable type support equipment listed in NavAir Allowance Lists, Section "G," "O," "R 5," "T," and "TBA's." Accountable AMSE items are those assigned material accountability recoverability codes "D" and "E". These items are assigned material control code X which appears as part of the federal stock number identification.

Because stocks of AMSE are so limited, issues are strictly controlled to insure proper program support. After initial outfitting, AMSE items are issued on an item-for-item exchange basis. When an AMSE item is lost, missing, or beyond economical repair, and replacement is required, approval of the replacement item is granted only when accompanied by a copy of the survey document. Aircraft maintenance support equipment is issued by the supply activity to the end user only upon approval by the following:

1. The cognizant type commander or his designated representative for fleet and training command activities.
2. The cognizant NavAirSysComRep for Naval Air Rework Facilities and shore activities.
3. ASO for special programs, bailment programs, military aid programs (MAP), etc.

Aircraft maintenance support equipment includes such items as test stands, lubricating guns, special wrenches, drills, compass testers, and voltmeters as listed in the Allowance Lists mentioned above. These equipments are made available as organizational property or custody/subcustody from supporting station/squadron/vessel dependent upon the characteristics of the equipment and the assigned maintenance, operational, and/or logistics responsibilities. Except for vessels, equipments required are authorized through the application of appropriate allowance lists as shown in enclosure (2) to BuWeps Instructions 04700.3. This enclosure consists of an allowance list applicability chart (ALAC) for each activity of the naval shore establishment indicating the equipment by allowance list category authorized to specific activities. Actual equipment authorized for naval vessels may be determined from BuWeps Instruction 4423.3 (Series).

Under the aircraft maintenance material readiness list (AMMRL) program all applicable intermediate and/or organizational maintenance support equipment listed in the various allowance lists are consolidated into one individual material readiness list (IMRL) for each aircraft maintenance activity. Each IMRL is approved by the cognizant fleet or training command and is used as the firm mandatory material readiness list of the activity to which the list applies.

All aircraft maintenance support equipment must receive continued accountability while in use. The activity having prime custody of the support equipment is considered to be the accountable activity. Equipment furnished as organizational property is accountable activity. Equipment furnished as organizational property is accounted for by the holder of such equipment. Equipment furnished or received on subcustody is accounted for by the supporting activity.

The department head is held responsible for the maintenance support equipment in his department. Senior Petty Officers normally are required to receipt on subcustody for all the AMSE in their shops. Periodic inventories are required to ascertain if material for which you are responsible is actually on hand. Material which cannot be accounted for must be surveyed.

An annual inventory of in-use aircraft maintenance support equipment is required to provide ASO and Naval Air Systems Command with an accurate assessment of the quantity and condition of this support equipment in the possession of custodians in order that sound decisions can be made concerning the procurement of new and replacement equipment. Type commanders or the NavAirSysComRep forwards to all activities having reportable items of support equipment a deck of EAM cards and/or an EAM listing indicating those items of support equipment requiring inventory. Care should be taken to insure that items held or issued on a custody basis are reported only by the controlling custodian.

Transaction reporting of selected AMSE items is sometimes required. Type commanders or the NavAirSysComRep selects the items of AMSE desired to be reported on a transaction basis and publish appropriate instructions for reporting. Upon receipt or transfer of an item of AMSE (subject to transaction reporting) on a permanent basis, or when the condition or status of equipment changes, activities are required to submit a transaction report.

HIGH VALUE ASSET CONTROL SYSTEM

The high value asset control system (HIVAC) is the result of SecNav Instruction P4440.29 (Series). This instruction prescribes a Navy-wide high value item management program. The purpose of the program is to achieve inventory economies without impairing combat readiness. In the past the military services have been critized for management deficiencies which led to accumulation of costly excess stocks.

The need for specialized, intensive management attention to a relatively small percentage of items can be better understood when considering the ever-increasing costs of weapon system and the increase in the costs of the major supporting spares and components for these systems. These costs have had an impact on the national economy approaching that of military expenditures of World War II.

By using the best techniques in the management of high value items, which represents approximately 40 percent of the annual procurement dollar expenditure, inventories and procurement investments can be reduced considerably and still maintain an acceptable level of readiness.

High value items, as described in BuSandA Instruction 4440.105 (Series), are identified by a specific material control (fraction) code on all supply documents as follows: Repairable items with a unit cost of $1,000 or more are assigned Material Code "G." Consumable items with a unit cost of $1,000 or more are assigned Material Code "J." There are control codes assigned to items other than those mentioned, but these two require worldwide movement accounting.

Although the technician is not directly involved in the program, he is involved at fleet level in that some of these items will be installed in aircraft or held in rotatable pools for which he may be required to assume responsibility. The major responsibility of fleet personnel is supply discipline, since supply discipline in the fleet is an especially critical aspect of the high value program. This is because of the greater difficulty of maintaining accountability under the pressure of operating conditions. Also, prompt action on the part of fleet personnel to expedite handling of high value items is essential to the program. For complete and detailed information concerning the HIVAC system, refer to the instructions previously mentioned in this section.

SURVEYING ACCOUNTABLE MATERIAL

When property must be reevaluated or expended from the records due to loss, damage, deterioration, or normal wear, a survey must be made to obtain proper authority to write this material off the books. The survey request provides a record showing the cause, condition, responsibility, recommendation for disposition, and authority to expend material from the records. Think of a survey as being an administrative examination into the cause of material being lost to use. Figure 17-2 shows the standard survey form that is used when a survey is made.

A survey may be either informal or formal, depending on the circumstances.

A formal survey is required for those classes of materials or articles so designated by the bureaus, commands, of offices concerned, or when specifically directed by the commanding officer. A formal survey is made by either a commissioned officer or a board of three officers. At least one of the board members must be a commissioned officer. The commanding officier appoints those who serve on the survey. Neither commanding officer, the officer on whose records the material being surveyed is carried, nor the officer charged with the custody of the material being surveyed, may serve on a survey board.

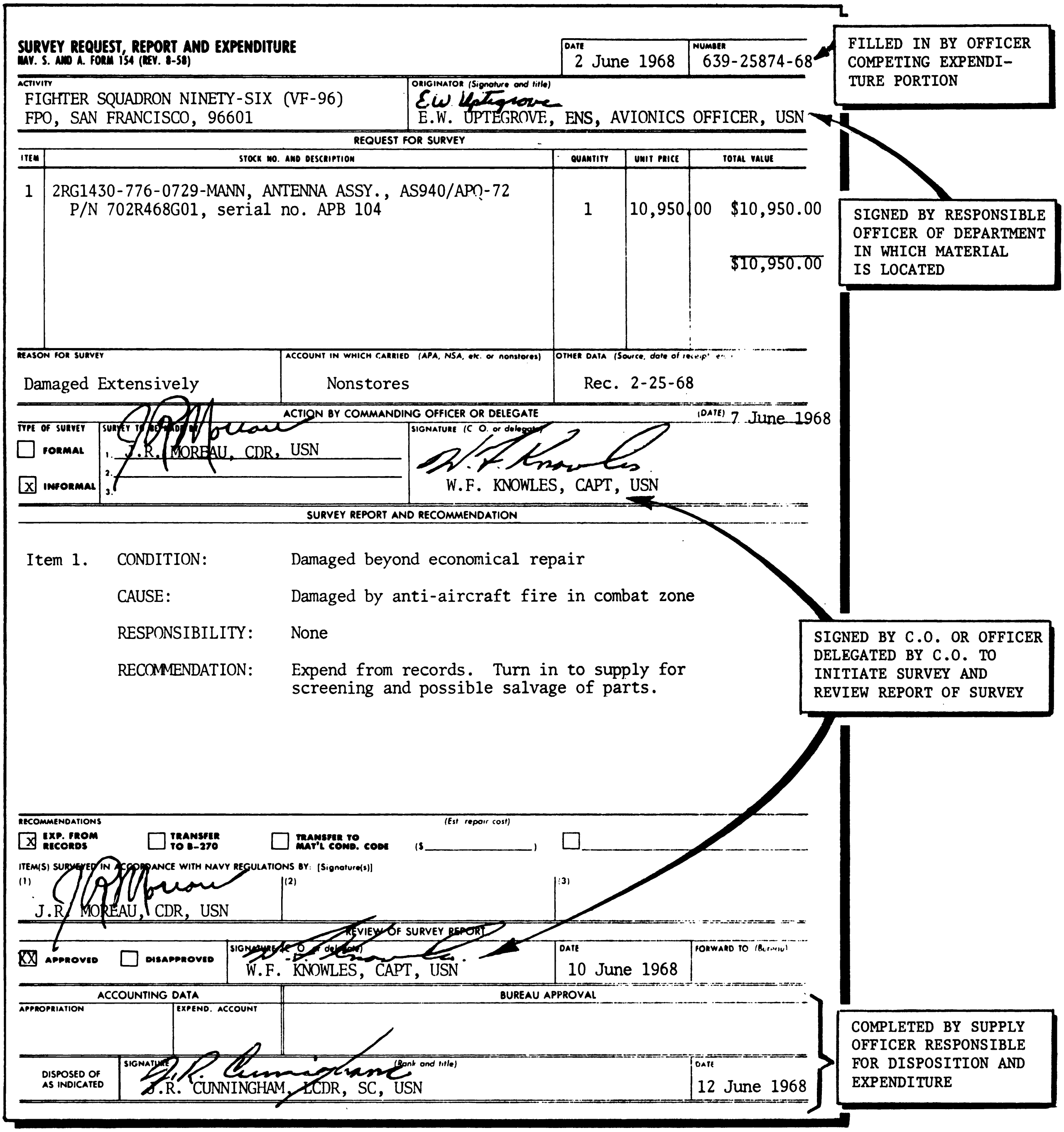
An informal survey is made by the head of the department having custody of the material to be surveyed. Informal surveys are used in all cases when a formal survey is not required or directed by the commanding officer.

Preparation of Request for Survey

You will not have the responsibility of preparing final survey forms; however, as a first class or chief, you are apt to be required to provide your division officer with certain information when he is making a survey. Because of this, you should be familiar with the general procedures that are followed.

A request for survey may be originated by a department, division, or section head or a designated subordinate as prescribed by local regulations. Normally, requests for survey are originated in the department having custody of the material being surveyed. The initial survey request is made on a rough copy of S. and A. Form 154. A statement by the originator is placed on or attached to the request for survey relative to the condition of material; cause of condition surrounding the loss, damage, deterioration, or obsolescence of material; responsibility for cause or condition of material or reason why responsibility cannot be determined; and recommended disposition of material or action to be taken.

Upon receipt of the rough copy, the designated group or section prepares a sufficient



SURVEY REQUEST, REPORT AND EXPENDITURE
NAV. S. AND A. FORM 154 (REV. 8-58)

DATE: 2 June 1968
NUMBER: 639-25874-68

FILLED IN BY OFFICER COMPETING EXPENDITURE PORTION

ACTIVITY: FIGHTER SQUADRON NINETY-SIX (VF-96)
FPO, SAN FRANCISCO, 96601

ORIGINATOR (Signature and title): EW Uptegrove
E.W. UPTEGROVE, ENS, AVIONICS OFFICER, USN

SIGNED BY RESPONSIBLE OFFICER OF DEPARTMENT IN WHICH MATERIAL IS LOCATED

REQUEST FOR SURVEY

ITEM	STOCK NO. AND DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL VALUE
1	2RG1430-776-0729-MANN, ANTENNA ASSY., AS940/APQ-72 P/N 702R468G01, serial no. APB 104	1	10,950.00	$10,950.00
				$10,950.00

REASON FOR SURVEY: Damaged Extensively
ACCOUNT IN WHICH CARRIED (APA, NSA, etc. or nonstores): Nonstores
OTHER DATA (Source, date of receipt etc.): Rec. 2-25-68

ACTION BY COMMANDING OFFICER OR DELEGATE (DATE) 7 June 1968

TYPE OF SURVEY
☐ FORMAL
☒ INFORMAL

SURVEY TO BE MADE BY
1. J.R. MOREAU, CDR, USN
2.
3.

SIGNATURE (C.O. or delegate): W.F. KNOWLES, CAPT, USN

SIGNED BY C.O. OR OFFICER DELEGATED BY C.O. TO INITIATE SURVEY AND REVIEW REPORT OF SURVEY

SURVEY REPORT AND RECOMMENDATION

Item 1. CONDITION: Damaged beyond economical repair
CAUSE: Damaged by anti-aircraft fire in combat zone
RESPONSIBILITY: None
RECOMMENDATION: Expend from records. Turn in to supply for screening and possible salvage of parts.

RECOMMENDATIONS
☒ EXP. FROM RECORDS
☐ TRANSFER TO B-270
☐ TRANSFER TO MAT'L COND. CODE
(Est repair cost) ($________)
☐ ________

ITEM(S) SURVEYED IN ACCORDANCE WITH NAVY REGULATIONS BY: (Signature(s))
(1) J.R. MOREAU, CDR, USN
(2)
(3)

REVIEW OF SURVEY REPORT
☒ APPROVED
☐ DISAPPROVED
SIGNATURE (C.O. or delegate): W.F. KNOWLES, CAPT, USN
DATE: 10 June 1968
FORWARD TO (Bureau):

ACCOUNTING DATA
APPROPRIATION:
EXPEND. ACCOUNT:
BUREAU APPROVAL:

DISPOSED OF AS INDICATED
SIGNATURE (Rank and title): J.R. CUNNINGHAM, LCDR, SC, USN
DATE: 12 June 1968

COMPLETED BY SUPPLY OFFICER RESPONSIBLE FOR DISPOSITION AND EXPENDITURE

AQ. 360

Figure 17-2.-Survey Request, Report, and Expediture (S. and A. Form 154).

number of smooth copies of the request for distribution in accordance with local regulations. The smooth survey request is filled out down to the caption Report. It is then forwarded to the commanding officer who will determine whether the survey will be formal or informal. If formal, the survey request is forwarded to the designated surveying officer(s);if informal,it is forwarded to the head of a department for survey action.

The statement by the originator as to cause, condition, etc., is attached to the smooth request for survey for evaluation by the surveying officer(s). After the survey has been completed by the head of a department or surveying officer(s), it is returned to the commanding officer for review and action. After approval by the commanding officer, the survey request is forwarded to the cognizant command for final review and approval when so required.

APPENDIX I

FIRE CONTROL SYMBOLS

GUNNERY AND ROCKET:

Symbol	Definition
R	Present range.
R_f	Future range.
T	Indicated temperature.
t_f	Time of flight of projectile.
t_fL	Lost time of flight.
V_G	Groundspeed.
V_o	Average projectile velocity.
V_m	Muzzle velocity.
V_M	Missile velocity.
V_A	True airspeed.
Λ	Total lead angle.
Λ_A	Azimuth component of total lead angle.
Λ_E	Elevation component of total lead angle.
Λ_b	Ballistic lead angle.
Λ_{bA}	Azimuth component of ballistic lead angle.
Λ_{bE}	Elevation component of ballistic lead angle.
Λ_k	Kinematic lead angle.
Λ_{kA}	Azimuth component of kinematic lead angle.
Λ_{kE}	Elevation component of kinematic lead angle.
Λ_{bW}	Windage factor of ballistic lead.
Λ_{bWE}	Elevation component of the windage factor.
Λ_{bWA}	Azimuth component of the windage factor.
Λ_{bG}	Gravity factor of ballistic lead.
Λ_{bGE}	Elevation component of gravity factor.
Λ_{bGA}	Azimuth component of gravity factor.
P	Antenna position.
P_A	Antenna position in azimuth.
P_E	Antenna position in elevation.
ω	Angular velocity.
ω_A	Angular velocity in azimuth.
ω_E	Angular velocity in elevation.
P_S	Static air pressure.
λ_o	Gravity drop factor.
A_A	Angle of attack.
A_S	Angle of skid.
A_L	Launcher angle.
T_R	Rocket propellant temperature.
R_o	Preset future range.
D	Air density.
t	Time.
$1/t_f$	Inverse time of flight.
$\dot{R}$	Range rate.
E	Error term.
E_R	Range error term (range coil voltage).
E_E	Elevation error term (elevation coil voltage).
E_A	Azimuth error term (azimuth coil voltage).
E_H	Heading error.

GUNNERY AND ROCKET—Continued

Symbol	Definition
E_{HE}	Heading error in elevation.
E_{HA}	Heading error in azimuth.
e_H	Steering error.
e_{HE}	Steering error in elevation.
e_{HA}	Steering error in azimuth.
a	Ballistic constant.
c	Ballistic constant.
T_d	Dome temperature.
N	Acceleration.
h	Ballistic constant (launching factor).
t_b	Rocket burn time.
V_b	Rocket burnt velocity.
V_o'	Velocity of projectile in vacuum.
ΔV_o	Decrease in velocity of projectile due to air drag.

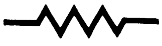
BOMBING:

Symbol	Definition
y	Magnetic variation.
θ	True heading.
θ_m	Magnetic heading.
θ_R	Relative bearing.
η	True course.
η_R	Relative course.
μ	True bearing.
V_W	Wind velocity.
${}_RV_W$	Range wind.
${}_\mu V_W$	Cross wind.
R	Horizontal range.
H_T	Target altitude above sea level.
H_A	Aim point altitude above sea level.
H_O	Aircraft altitude above sea level.
H	Aircraft altitude above aim point.
V_H	Vertical velocity.
T	Ballistics.
S	Horizontal offset of target from aim point.
ψ	Angular position of S vector from true north.
P_V	Pitot air pressure.
P_S	Static air pressure.
T_S	Stagnation temperature.
r	Slant range.
ϕ	Elevation angle of line of sight.
V_R	Range rate.
V_μ	Azimuth rate.
R_o	Initial horizontal range.
t	Time.
k	Drift angle.
μ_o	Initial true bearing.
γ	Nonlinear V_G.
T'	Trail (in feet).
Δ	Change in a quantity when used as a prefix.
t_f	Time of fall.

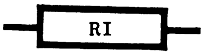
APPENDIX II

ELECTRONIC SYMBOLS

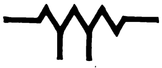
RESISTORS:



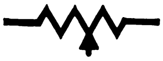
OR



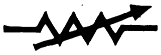
GENERAL



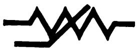
TAPPED



ADJUSTABLE TAP

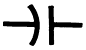


CONTINUOUSLY VARIABLE

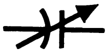


NONLINEAR

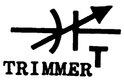
CAPACITORS:



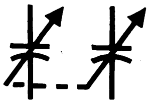
FIXED



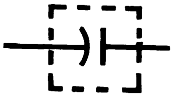
VARIABLE



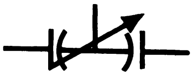
TRIMMER



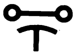
GANGED



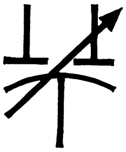
SHIELDED



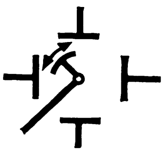
SPLIT-STATOR



FEED-THROUGH



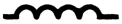
DIFFERENTIAL



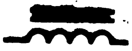
PHASE SHIFT

(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

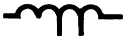
INDUCTIVE COMPONENTS



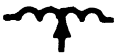
GENERAL



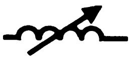
MAGNETIC CORE



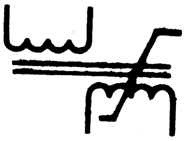
TAPPED



ADJUSTABLE

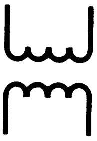


ADJUSTABLE OR CONTINUOUSLY ADJUSTABLE

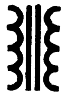


SATURABLE CORE REACTOR

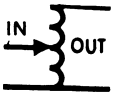
TRANSFORMERS



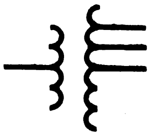
GENERAL



MAGNETIC CORE TRANSFORMER

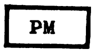


AUTOTRANSFORMER

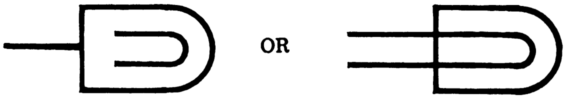


WITH TAPS, SINGLE-PHASE

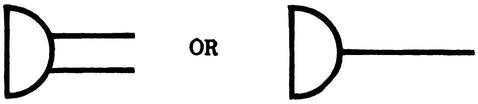
PERMANENT MAGNET



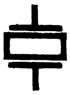
INDICATOR LAMP



MICROPHONE

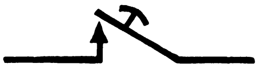


CRYSTAL



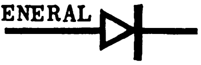
QUARTZ CRYSTAL;
PIEZOELECTRIC CRYSTAL
UNIT.

KEY

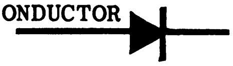


RECTIFIER

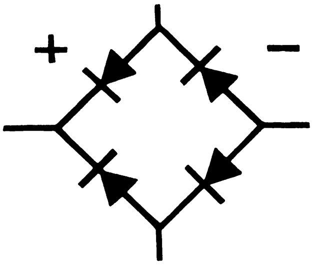
GENERAL



SEMICONDUCTOR

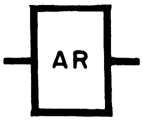


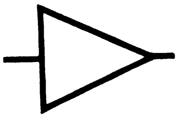
NORMAL CURRENT FLOW IS AGAINST THE ARROW



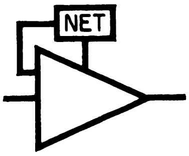
FULL WAVE BRIDGE TYPE

AMPLIFIER





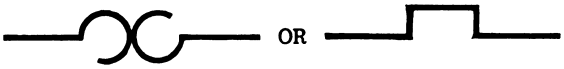
TRIANGLE POINTS
IN DIRECTION OF
TRANSMISSION
(SIGNAL FLOW)



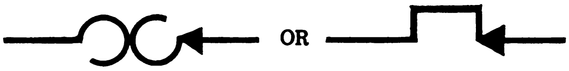
AMPLIFIER WITH
EXTERNAL
FEEDBACK PATH

BASIC SYMBOL INDICATES ANY METHOD OF AMPLIFICATION EXCEPT THAT OPERATING ON THE PRINCIPLE OF ROTATING MACHINERY.

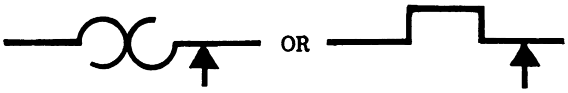
THERMAL ELEMENTS

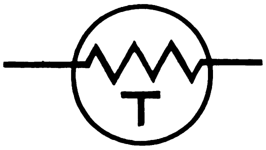


THERMAL RELAY WITH
NORMALLY CLOSED
CONTACT.

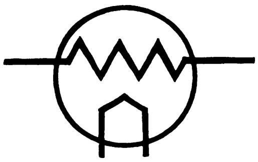


FLASHER; THERMAL CUTOUT

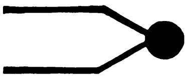




THERMISTOR

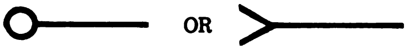


WITH INTEGRAL
HEATING ELEMENT

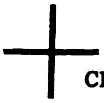


TEMPERATURE-MEASURING THERMOCOUPLE
(DISSIMILAR METAL DEVICE)

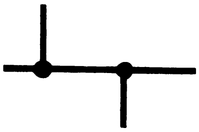
INPUTS (NONSTANDARD)



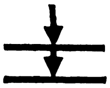
PATH, TRANSMISSION



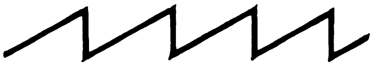
CROSSING NOT
CONNECTED



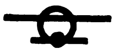
JUNCTION CONNECTED



TWISTED PAIR

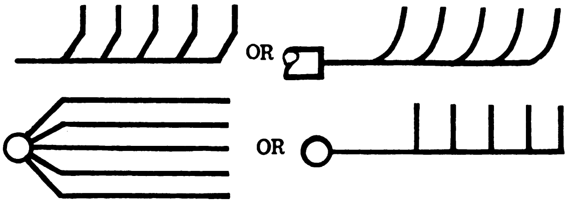


AIR OR SPACE PATH



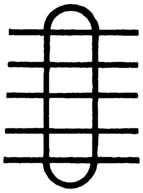
COAXIAL

GROUPING OF WIRES IN BUNDLES

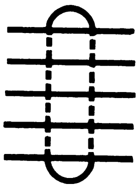


GROUPING OF WIRES IN CABLES

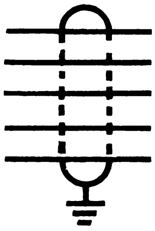
CABLES



FIVE-
CONDUCTOR
CABLE



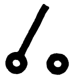
SHIELDED
FIVE-CONDUCTOR
CABLE



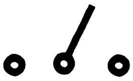
GROUNDED
SHIELD

NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY

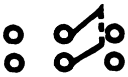
SWITCHES



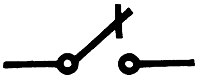
GENERAL
(SINGLE THROW)



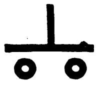
GENERAL
(DOUBLE THROW)



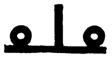
TWO POLE
DOUBLE THROW
SWITCH



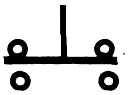
KNIFE SWITCH



PUSHBUTTON
(MAKE)

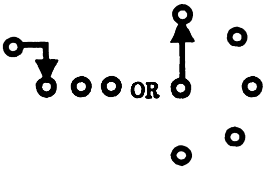


PUSHBUTTON
(BREAK)



PUSHBUTTON TWO CIRCUIT

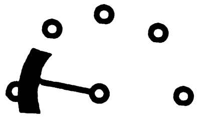
SELECTOR SWITCHES

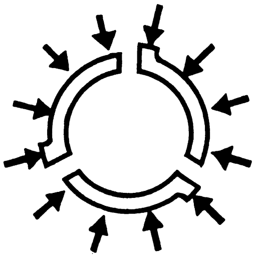


GENERAL

ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK BEFORE MAKE SWITCH.

MAKE BEFORE BREAK

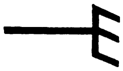




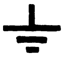
WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

CIRCUIT RETURNS

CHASSIS CONNECTION



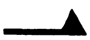
(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)



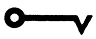
GROUND

CONTACTS (ELECTRICAL)

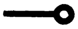
SWITCH



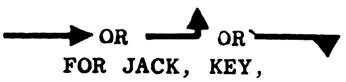
MOMENTARY
SWITCH



LOCKING



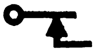
NONLOCKING



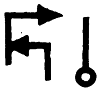
FOR JACK, KEY,
RELAY, ETC.

CONTACTS (ELECTRICAL) (Continued)

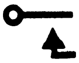
CONTACT ASSEMBLIES



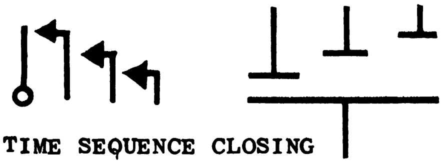
CLOSED CONTACT
(BREAK)



MAKE BEFORE
BREAK

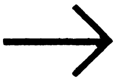


OPEN CONTACT
(MAKE)

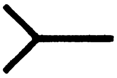


TIME SEQUENCE CLOSING

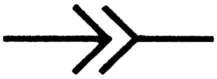
DISCONNECTING DEVICES



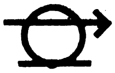
MALE
(PIN CONTACT)



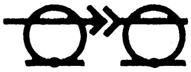
FEMALE
(SOCKET CONTACT)



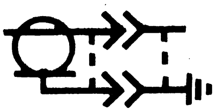
ENGAGED
(PIN-TO-SOCKET)



COAXIAL
(MALE)

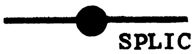


COAXIAL CONNECTORS
MATED

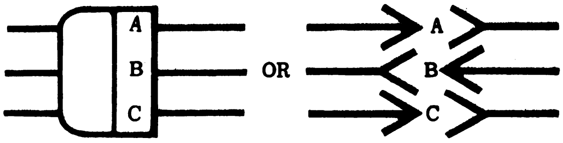


COAXIAL CONNECTED
TO SINGLE CONDUCTOR

THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.



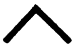
SPLICE



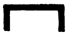
CONNECTOR ASSEMBLY (GENERAL)

ELECTRON TUBES

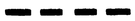
COMPONENT TUBE SYMBOLS



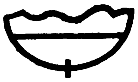
DIRECTLY-HEATED
(FILAMENTARY)
CATHODE



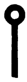
INDIRECTLY-HEATED
CATHODE



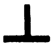
GRID



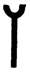
POOL CATHODE



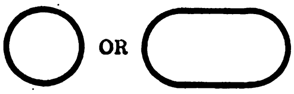
COLD
CATHODE



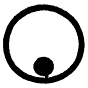
ANODE OR
PLATE



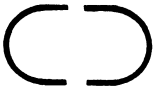
PHOTOCATHODE



ENVELOPE (SHELL)

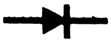


GAS FILLED
ENVELOPE

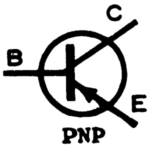


SPLIT ENVELOPE

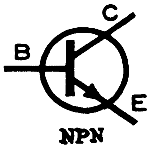
SEMICONDUCTOR DEVICES



DIODE

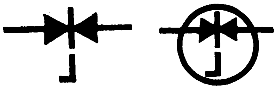


PNP

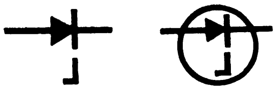


NPN

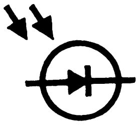
TRANSISTORS



BREAKDOWN DIODE,
BIDIRECTIONAL

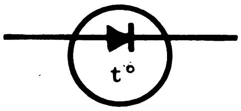


BREAKDOWN DIODE,
UNDIRECTIONAL
(ALSO BACKWARD DIODE)

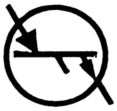


PHOTODIODE

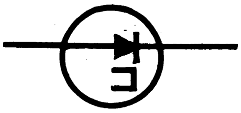
SEMICONDUCTOR DEVICES: (Continued)



TEMPERATURE
DEPENDENT DIODE

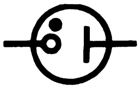


PNPN SWITCH

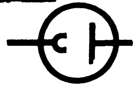


TUNNEL DIODE

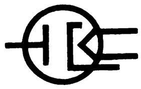
TYPICAL ELECTRON TUBES



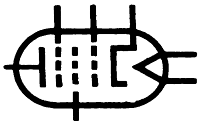
COLD CATHODE
GAS TUBE



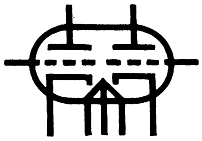
PHOTOTUBE SINGLE
UNIT, VACUUM



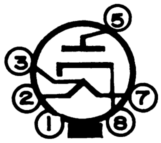
DIODE



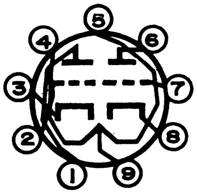
PENTODE



TWIN TRIODE
ILLUSTRATING
ELONGATED ENVELOPE

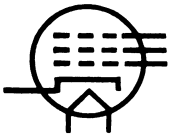


DIODE SHOWING BASE
CONNECTIONS

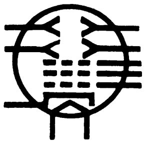


TWIN TRIODE WITH TAPPED HEATER

TYPICAL CATHODE RAY TUBES

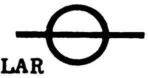


MAGNETIC DEFLECTION

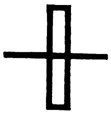


ELECTROSTATIC
DEFLECTION

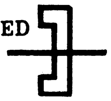
WAVEGUIDES



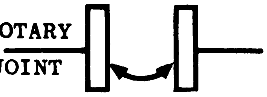
CIRCULAR



RECTANGULAR

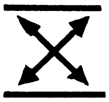


RIDGED

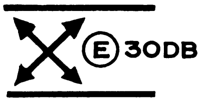


ROTARY
JOINT

DIRECTIONAL COUPLERS



GENERAL

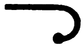


E PLANE APERTURE
COUPLING, 30 DB
TRANSMISSION LOSS

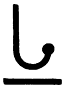
COUPLING METHODS

GENERALLY USED FOR COAXIAL
AND WAVEGUIDE TRANSMISSION.

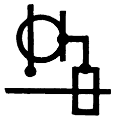
COUPLING BY APERTURE WITH AN
OPENING OF LESS THAN FULL
WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN
CIRCLE (E, H, OR HE).



COUPLING BY LOOP TO SPACE

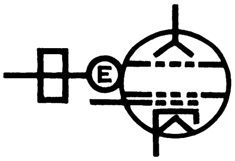


COUPLING BY LOOP TO GUIDED
TRANSMISSION PATH



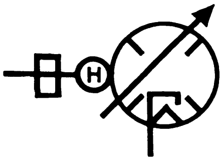
COUPLING BY PROBE FROM COAXIAL TO
RECTANGULAR WAVEGUIDE WITH DIRECT-CURRENT GROUNDS CONNECTED

TYPICAL MAGNETRONS AND KLYSTRONS

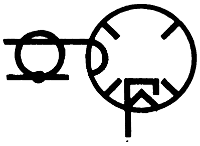


REFLEX KLYSTRON,
APERATURE COUPLED

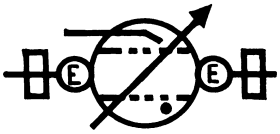
TUNABLE MAGNETRON,
APERTURE COUPLED



TYPICAL MAGNETRONS AND KLYSTRONS (Continued)

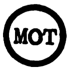


RESONANT TYPE WITH COAXIAL OUTPUT

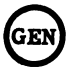


TRANSMIT-RECEIVE (TR) TUBE GAS FILLED, TUNABLE INTEGRAL CAVITY, APERTURE COUPLED, WITH STARTER

ROTATING MACHINES

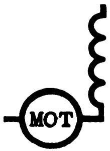


MOTOR

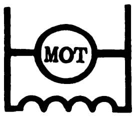


GENERATOR

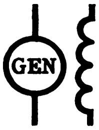
TYPES OF WINDINGS



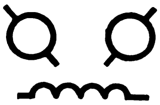
SERIES



SHUNT

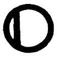


SEPARATELY EXCITED

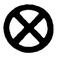


DYNAMOTOR

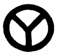
WINDING SYMBOLS



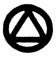
SINGLE-PHASE



TWO - PHASE



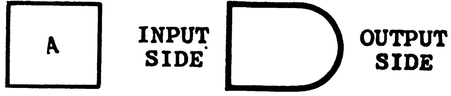
THREE-PHASE (WYE)



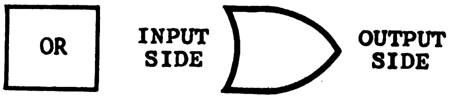
THREE-PHASE (DELTA)

LOGIC FUNCTIONS

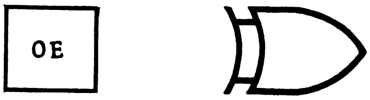
AND FUNCTION



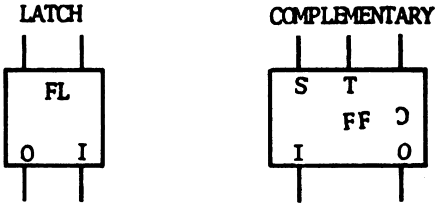
INCLUSIVE OR FUNCTION



EXCLUSIVE OR FUNCTION



FLIP-FLOPS

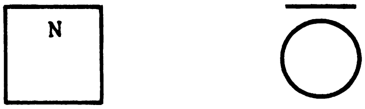


S-SET T-TRIGGER C-CLEAR

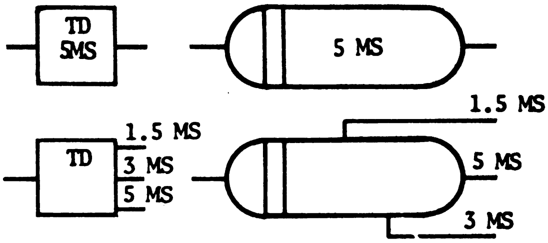
NEGATION

0

ELECTRIC INVERTER

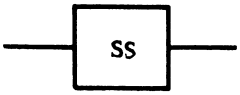


TIME DELAY

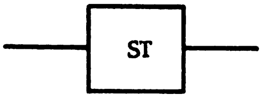


LOGIC FUNCTIONS (Continued)

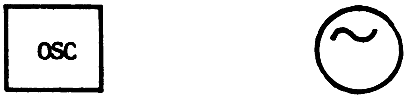
SINGLE SHOT



SCHMITT TRIGGER

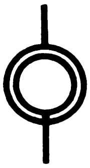


OSCILLATOR



SYNCHROS

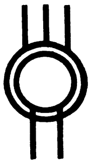
GENERAL



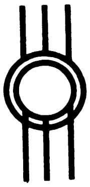
A LETTER COMBINATION FROM THE FOLLOWING LIST MAY BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

TX - TORQUE TRANSMITTER
TDX - TORQUE DIFFERENTIAL TRANSMITTER
CX - CONTROL TRANSMITTER
CDX - CONTROL DIFFERENTIAL TRANSMITTER
TR - TORQUE RECEIVER
CT - CONTROL TRANSFORMER

SYNCHROS (Continued)

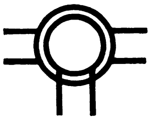


TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

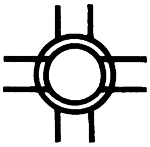


DIFFERENTIAL TRANSMITTER OR RECEIVER

RESOLVER (SYNCHRO)

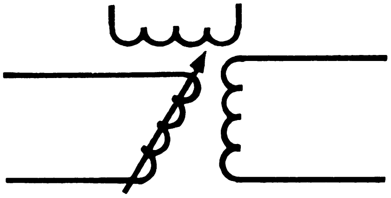


SINGLY-WOUND ROTOR

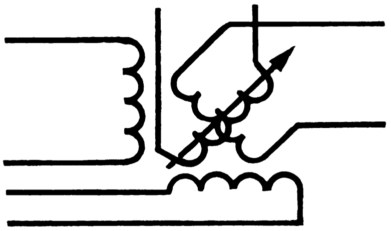


DOUBLY-WOUND ROTOR

RESOLVER

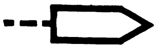


SINGLY-WOUND ROTOR

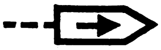


DOUBLY-WOUND ROTOR

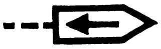
PICKUP HEADS



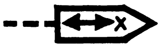
GENERAL



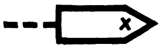
WRITING; RECORDING; HEAD,
SOUND RECORDER



READING; PLAYBACK; HEAD,
SOUND REPRODUCER

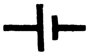


APPLICATION: WRITING, READING,
AND ERASING

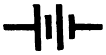


ERASING; ERASER, MAGNETIC

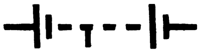
BATTERIES



ONE CELL



MULTICELL

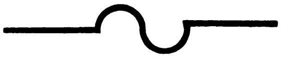


TAPPED
MULTICELL

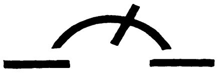
(LONG LINE IS ALWAYS POSITIVE)

CIRCUIT PROTECTORS

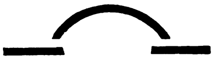
FUSE



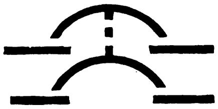
CIRCUIT BREAKERS



SWITCH

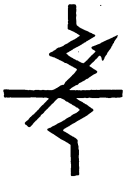


PUSH PULL OR PUSH

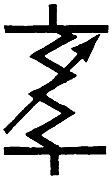


GANGED

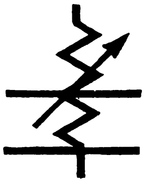
ATTENUATORS



GENERAL



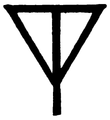
BALANCED



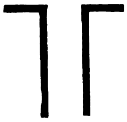
UNBALANCED

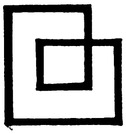
ANTENNAS

GENERAL

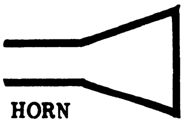


DIPOLE



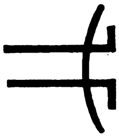


LOOP



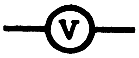
HORN

PARABOLIC



(NONSTANDARD)

METERS



A - AMMETER

CRO - OSCILLOSCOPE

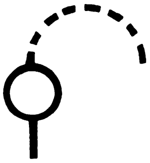
G - GALVANOMETER

MA - MILLIAMMETER

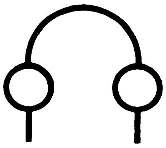
OHM - OHMMETER

V - VOLTMETER

HEADSET



OR



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